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16. ABSTRACT

This report is a review of environmental levels of cadmium based on published reports and other information sources. Cadmium levels are reported for the atmosphere, surface and ground waters, drinking water, sediments, soil, sludge, terrestrial and aquatic biota, and man. The behavior of cadmium in the environment is also discussed. Although cadmium is present in measurable quantities in virtually all areas, for the general population oral ingestion in foods can represent the most important source of cadmium intake. Airborne sources appear to constitute a significant portion of cadmium intake for those occupationally exposed or those residing in areas heavily polluted by cadmium-emitting industries. Based on the information in this document, current cadmium releases to the environment appear to be declining. However, the cadmium content in fossil fuels and fertilizers is only partially controllable, and these two sources may set the lower bounds of attainable minimums in cadmium emissions to the environment. Most of the dissipated cadmium eventually becomes bound to soil, sediment, and ocean sinks. Biological accumulations of cadmium are found in most living organisms.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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Water	Behavior		
Sediment			
Soil			
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Biota			
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PREFACE

This review of the environmental levels of cadmium was conducted for the U.S. Environmental Protection Agency, Office of Toxic Substances, under Contract Number 68-01-1983. It involved (1) the review and evaluation of existing monitoring data and (2) development of an integrated data package. Information sources were identified from computerized and manual searches. Data were obtained from specialized data centers; university programs; federal programs; state programs; the Smithsonian Science Information Exchange; EPA's Storet, SAROAD, and NASN data centers; the USGS, and Fish and Wildlife Service; and from readily available open literature.

Information gathered included cadmium concentrations in air, surface and drinking water, groundwater, soil, food, sediment, sludge, aquatic and terrestrial organisms, human tissues, and body fluids. Details were obtained on the methods of sample collection, interferences, meteorological data, and analytical methods employed.

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cadmium in their bodies. Exceptions were domestic rabbits and mountain cottontails found in the polluted Helena Valley, Montana. Their levels were 7 to 16 times higher than those of cows, ground squirrels, and mice. No clear indication of any difference in the cadmium content of herbivorous and carnivorous animals were observed from the available data.

Knowledge gaps still exist on the behavior and fate of cadmium in atmospheric, terrestrial, and aquatic environments, but some statements can be made. Airborne cadmium particles are presumed to eventually return to the land and water environments, the major fallout appearing to be within a few kilometers from the source, e.g., a smelter stack. Soil receives cadmium directly from emission sources as land-destined wastes and fallout deposition from the atmosphere, the estimated amount being nearly 96 percent of the total environmental cadmium emissions. About 95 percent of this is retained in the soil, the remainder being leached or washed into streams. There is a lack of information on sedimentation losses of cadmium in the freshwater environment; thus the flux of cadmium from freshwater streams into the oceans can only be estimated.

Although cadmium is present in measurable quantities in virtually all areas, for the general population oral ingestion in foods can represent the most important source of cadmium intake. Airborne sources appear to constitute a significant portion of cadmium intake for those occupationally exposed or those residing in areas heavily polluted by cadmium-emitting industries. Data from the FDA's Total Diet Studies indicate no trend of increasing or decreasing cadmium exposure from foods during the period 1968 through 1974.

The estimated biological half-life of cadmium in man is from 13 to 47 years. The average body burden of cadmium in adults in the United States is reported to be 15 to 20 mg. This is reflected by increased concentrations in the kidney, liver, pancreas, and blood vessels. The adult American male nonsmokers with mean age of 60 have, on the average, a total body burden of 13 mg of cadmium. In contrast, the adult cigarette smokers have a total body burden of 30 to 40 mg. Studies of cadmium levels in whole blood in normal, nonexposed human populations generally reveal whole blood cadmium levels of less than 1 ng/100 ml but in exposed workers the range may be 1 to 10 ng/100 ml.

Based on the information in this document, current cadmium releases to the environment appear to be declining. However, the cadmium content in fossil fuels and fertilizers is only partially controllable, and these two sources may set the lower bounds of attainable minimums in cadmium emissions to the environment. Most of the dissipated cadmium eventually becomes bound to soil, sediment, and ocean sinks. Biological accumulations of cadmium are found in most living organisms.

1. INTRODUCTION

PHYSICAL AND CHEMICAL PROPERTIES

Cadmium is a relatively rare element in the earth's crust, ranking in abundance between mercury and silver, 0.1 to 0.5 ppm, and does not occur in sufficient abundance to be mined as an ore. Cadmium is a soft metal with low melting and boiling points, 312 C and 765 C, respectively. These physical properties account for its volatility and high vapor pressures encountered at only moderate temperatures and contribute to its release to the atmosphere through the pyrometallurgical operations in its recovery from ores and in welding and torch cutting, and from incineration of wastes and the combustion of coal. However, ambient concentrations of cadmium in the air are, in general, of the order of a few hundredths or thousandths of a microgram per cubic meter, suggesting the existence of an effective removal mechanism (fallout and rainout). More detailed information is available in Hammons and Huff (1975).

Cadmium sulfide (CdS), carbonate ($CdCO_3$), and oxide (CdO) are insoluble compounds. The hydroxide, $Cd(OH)_2$, is also insoluble and can be precipitated from solution by the addition of hydroxide ion (OH^-). Unlike zinc hydroxide, cadmium hydroxide does not redissolve in excess hydroxide (Fulkerson and Goeller, 1973). Because of the low solubility of the carbonate and the sulfide, the amount of cadmium which can remain dissolved in natural waters is quite low. Additionally, in waters free of sulfide or any complex-forming ligands, dissolved cadmium concentrations can be very low as a result of the equally low solubilities of the carbonate. In nonacid waters, at a pH less than 9.5 and with $<10^{-5}$ M total carbonate, the concentration of dissolved cadmium can be as low as a few parts per billion (Fulkerson and Goeller, 1973). Nearly all of the U.S. Geological Survey benchmark surface water stations which are discussed later exhibit dissolved cadmium concentrations of this order of magnitude, where cadmium was detectable at all. Most cadmium found in aquatic systems tends to be associated with particulates.

PRODUCTION AND USES OF CADMIUM

Production

Cadmium is one of the lesser nonferrous metals, produced almost totally as a by-product of zinc mining and smelting. Annual consumption in the U.S. has during the last several years averaged around 5,000 metric tons (De Filippo, 1975). Although the U.S. has been the leading producer for over half a century, that portion of domestic consumption which is produced by the U.S. has steadily declined. Nearly 40 percent of U.S. demands are now imported. In 1974, domestic demand, 5,600 metric tons (6,200 short tons), was 33 percent of world production.

Uses

Total U.S. cadmium consumption in recent years has been in the range of 4,000 to 6,000 metric tons/year and is expected to reach about 10,000 metric tons annually. The uses of cadmium are almost totally dissipative; there is no significant recycling. Although data on the ultimate end use of cadmium are sparse, the largest single use which consumed about 46 percent of the total (2,700 metric tons) in 1974 is for electroplating and coating, including that for transportation uses. Cadmium is widely used for plating motor vehicle parts, aircraft parts, marine equipment, hardware, household appliances, and miscellaneous industrial machinery parts (nuts, bolts, springs, washers, rivets, and other fasteners) to prevent corrosion (De Filippo, 1975).

Cadmium has many superior properties compared to competitive materials for corrosion protection and its use is likely to continue, at least in the near term. The properties of cadmium which have led to its widespread use in electroplating include the following: (1) good protection from only a thin coating, (2) low electrical resistance of plated contacts, (3) retention of luster for long periods, (4) ease of soldering plated parts, (5) good corrosion resistance to salt water and alkalies, (6) uniform deposition on intricately shaped objects, and (7) little effect on strength of steel parts stressed in high-temperature service (Heindl, 1971).

The second largest use (~1,000 metric tons in 1974) is for paint pigments; cadmium sulfide, yellow to orange, and cadmium sulfoselenide, orange to deep maroon, are the most widely used pigments.

Cadmium salts of long-chain organic acids are used as plasticizers and heat stabilizers for plastics, ~900 metric tons in 1974. However, because of its toxicity, cadmium cannot be used in plastics for food containers.

The only other identified use of significance, 550 metric tons in 1974, is in nickel-cadmium batteries. There are a number of other uses. Cadmium has a very high neutron-absorbing cross section and is accordingly used in nuclear reactor controls. It finds some use in fluorescent phosphors, in low-melting alloys, in bearing alloys, and in brazing alloys and solders. Total consumption for other uses in 1974 was approximately 450 metric tons.

Figure 1.1 represents U.S. cadmium consumption in 1975. In contrast to 1974, plastics stabilization utilized more cadmium than the processes involved in developing pigments.

The forecasts by the U.S. Bureau of Mines for the year 2000 estimate cadmium consumption to lie between 8,400 and 15,600 metric tons (9,300 to

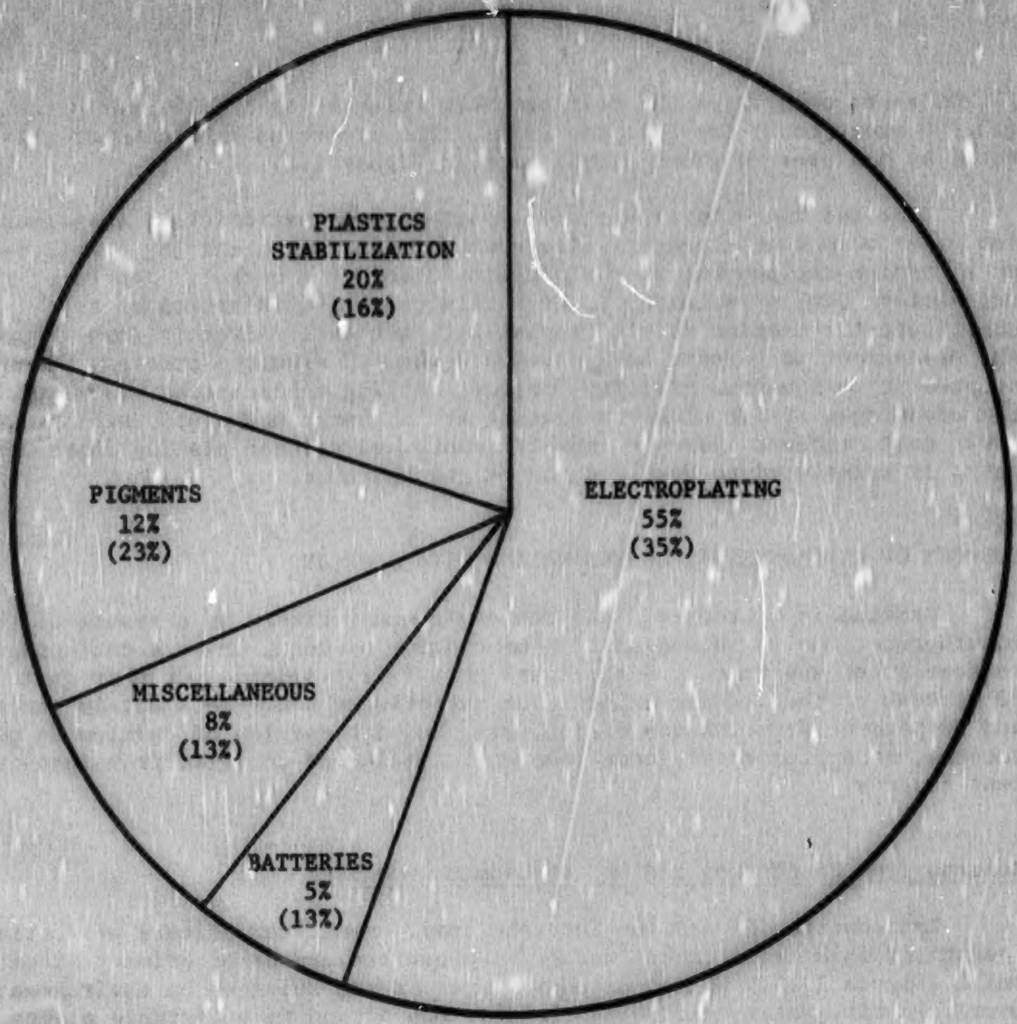

Figure 1.1. U.S. cadmium consumption in 1975 (American Metal Market, 1975). Figures in parentheses represent consumption in 1975 for U.S., West Germany, Britain, and Japan (Anonymous, 1977).

17,200 short tons) with the most probable value being 11,500 metric tons (12,700 short tons) (De Filippo, 1975). The projected breakdown of this total by end uses is shown graphically in Figure 1.2.

Zinc and zinc-tin alloys are expected to be satisfactory substitutes for cadmium in some electroplating uses. Organotins are being considered as a cadmium replacement in the plastics stabilizer market. Ion Vapor Deposition (IVD) of aluminum is currently under consideration as a substitute for cadmium in electroplating. McDonnell Aircraft Company and the Department of Defense have developed the IVD aluminum process and have adapted it to numerous military aircraft coating applications. Some of the advantages of IVD aluminum plating are higher temperature usability, lower cost, reduced hydrogen embrittlement, and reduced plating thickness which is translated to both reduced weight and cost.

SOURCES OF ENVIRONMENTAL CONTAMINATION WITH CADMIUM

Cadmium is introduced into the environment either as a result of the manufacture, use, or disposal of some cadmium product, or as a contaminant in some other substance. Sargent and Metz (1975) pointed out that while 20 percent of the release arises from the primary nonferrous metals industry, and 30 percent from the conversion, use, and disposition of cadmium in our economy, an approximately equal amount is estimated to arise from inadvertent sources.

Release from Production and Use of Cadmium Products

Introduction of cadmium into the environment from primary production operations is a fairly localized problem and the number of primary sites is small (Figure 1.3). While, as shown later in the sections on environmental levels in air, water, and soil, the environs around many of these plants received significant cadmium burdens in past years, the trend now is toward effective control of emissions. Incremental burdens in future years are, therefore, being reduced.

The cadmium-consuming industry is geographically somewhat concentrated. Fulkerson and Goeller (1973), reporting to a 1960 U.S. Bureau of Mines survey, noted that approximately 58 percent of the cadmium-consuming industry of the United States was in states bordering the Great Lakes. The remaining 28 percent of the consuming industry was distributed among the other states. Thus, releases of cadmium to the environment from manufacture, use, and disposal would be expected to follow a similar geographic distribution (Figure 1.4).

An assessment of industrial hazardous waste practices in the electroplating and metal-finishing industries (U.S. Environmental Protection Agency, 1975b) developed a model of the geographic distribution of independent job shop platers based upon survey response (Figure 1.5).

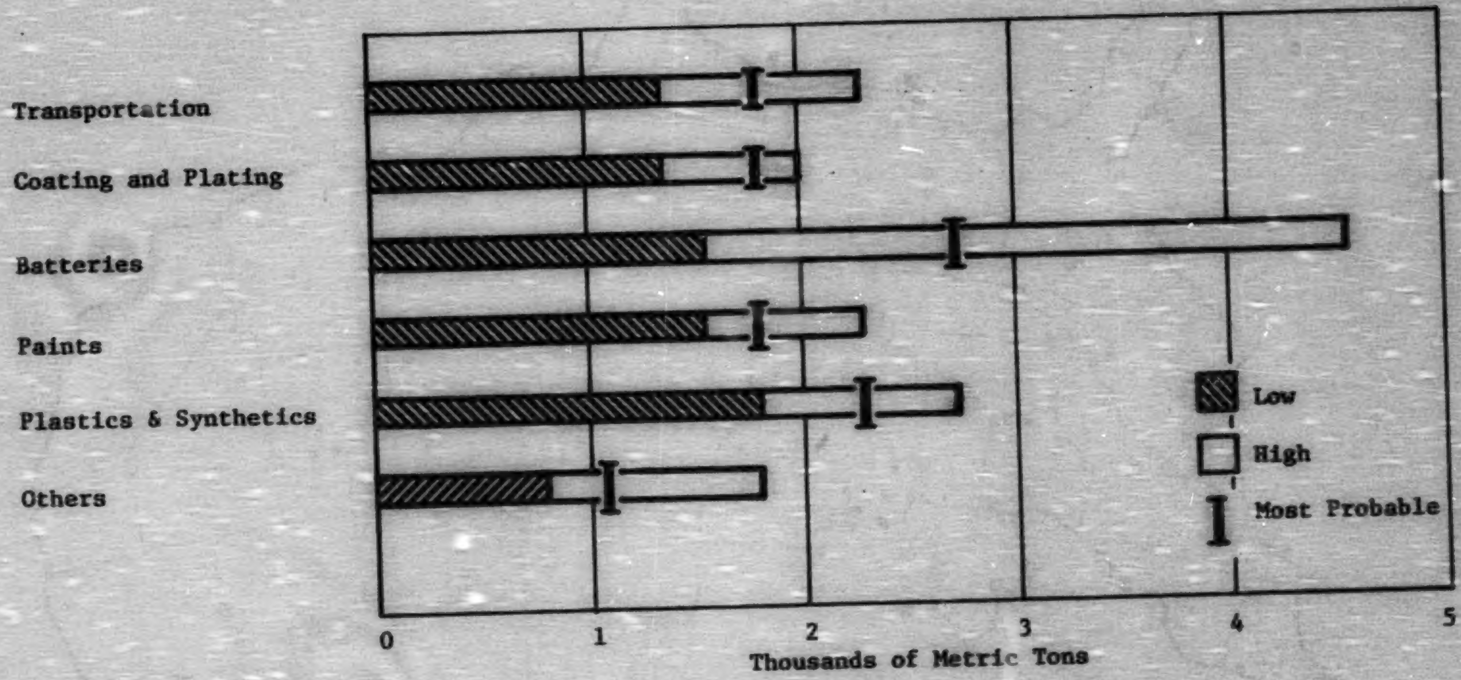

Figure 1.2. Projected cadmium consumption in the United States by end use, year 2000.

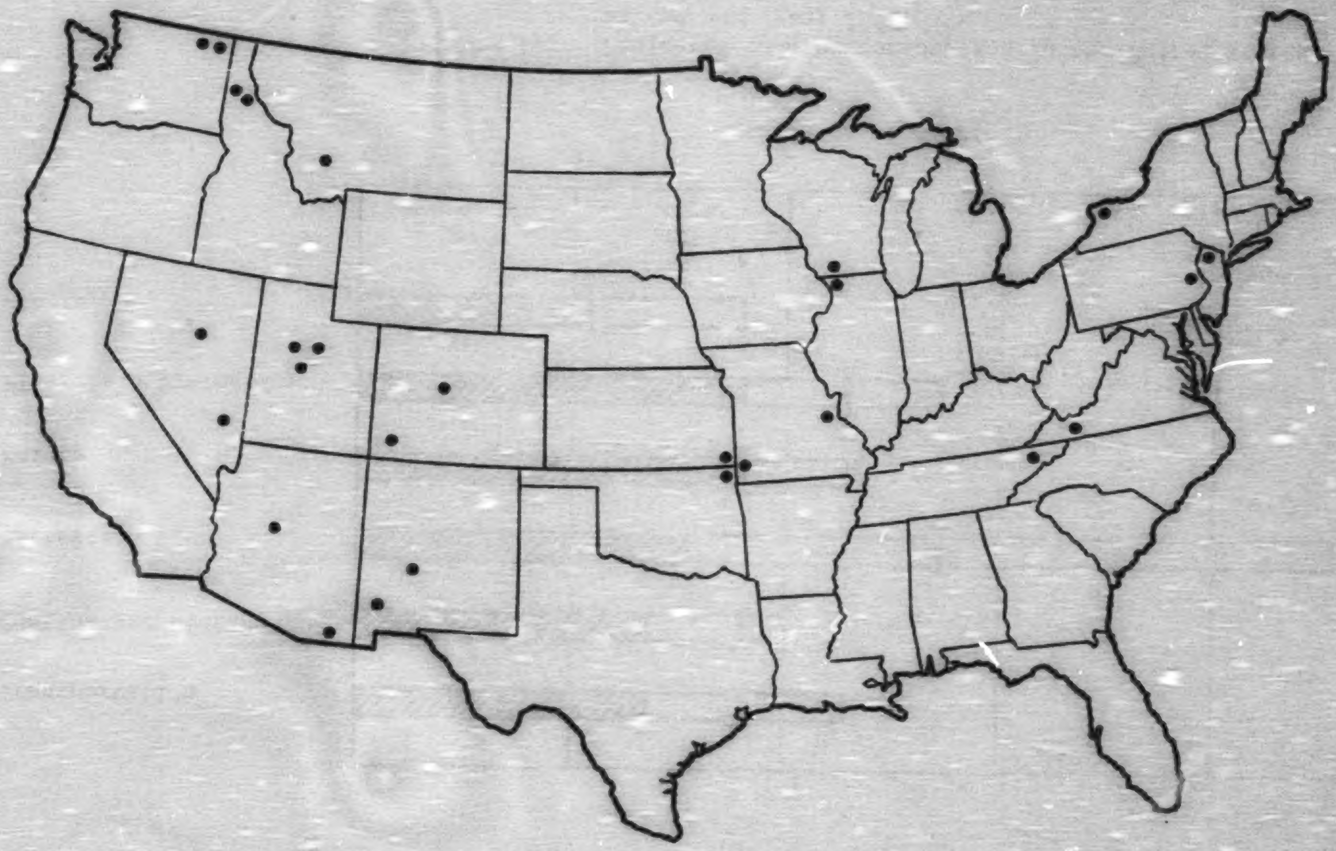

Figure 1.3. Geographical distribution of recoverable zinc resources in the United States (Wedow, 1973).

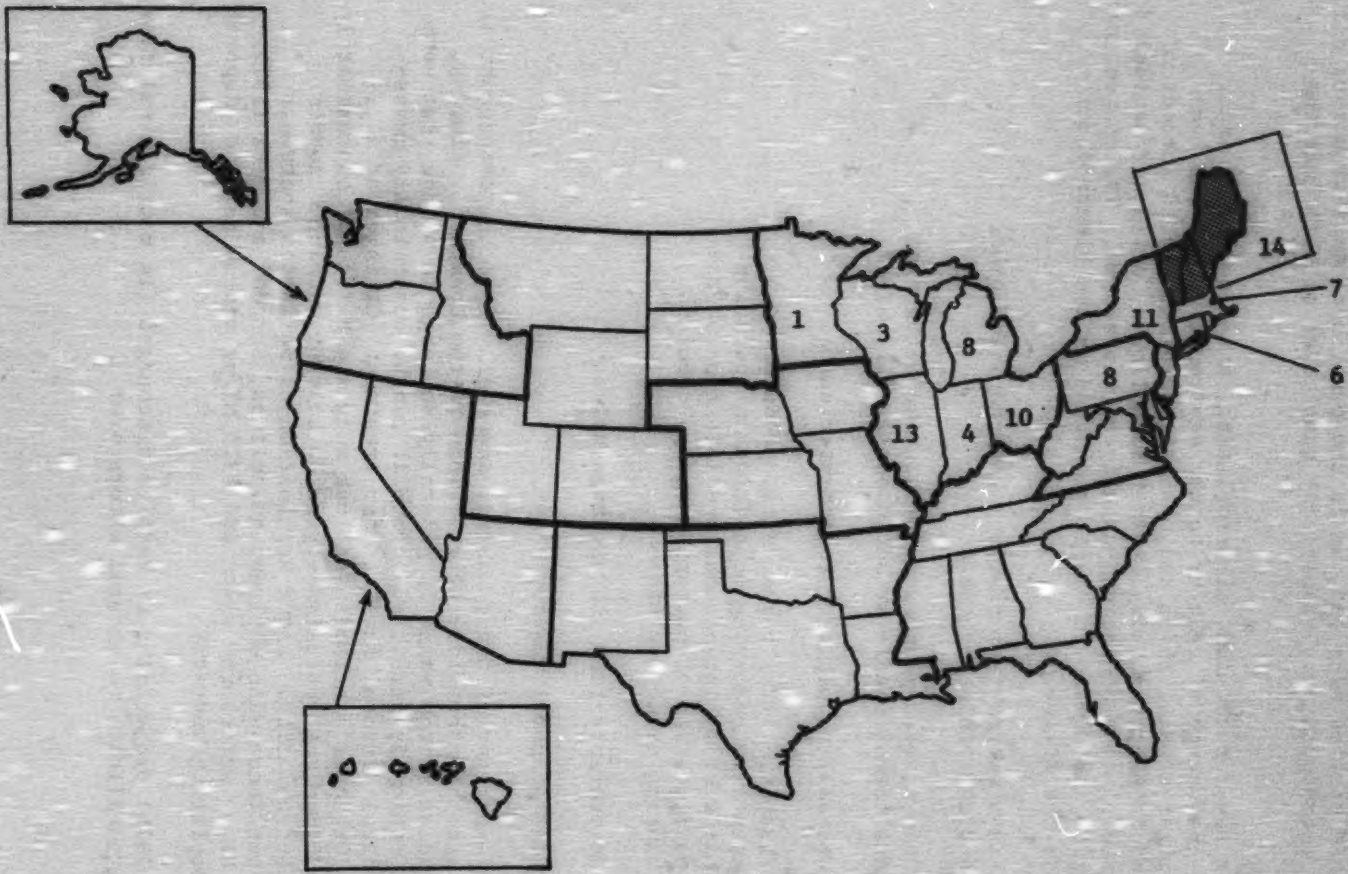
14
7
11
6
1
3
8
8
13
4
10

Figure 1.4. Cadmium consumption (percent) by state. Remaining 37 states--28% (Fulkerson and Goeller, 1973).

Cadmium is associated with all zinc ores and is a by-product of the zinc industry. Its removal from zinc is necessary and would be performed even in the absence of a market for cadmium. Cadmium follows the zinc through the beneficiation step and, as in the past, effluents from zinc mill tailings ponds introduced very significant quantities of both into the environment.

The major use for cadmium, electroplating, has also been a major contributor to the escape of cadmium to the environment. It has been estimated (Ottinger et al., 1973a and b) that approximately 18 percent of the cadmium used in electroplating is lost as a liquid, solid, or semisolid sludge during the plating operation, usually to the sewers. The sources of the liquid, solid, and semisolid wastes generated in the electroplating industry include the following:

- Rinse waters from plating, cleaning, and other surface finishing operations
- Concentrated plating and finishing baths that are intentionally or accidentally discharged
- Wastes from plant or equipment cleanup
- Sludges, filter cakes, etc., produced by naturally occurring deposition in operating baths or by intentional precipitation in the purification of operating baths, chemical rinsing circuits, etc.
- Regenerants from ion exchange units
- Vent scrubber waters.

The most important of these wastes, especially from the standpoint of the smaller plater, is the rinse water. This is the constantly flowing, production-oriented stream which is generally so large in volume that some form of concentration is warranted before it can be economically transported to a central disposal facility for treatment (Ottinger et al., 1973a and b). Ottinger's estimate of loss suggests a loss of approximately 490 metric tons from the approximately 2,700 tons of cadmium consumed annually in electroplating. After application of pollution abatement practices in compliance with effluent guidelines, Sargent and Metz (1975) estimate 10.5 MT/yr waterborne waste and 73.5 MT/yr wastes to land disposal for the electroplating industry.

Yost's (1976) projections of cadmium discharged (in metric tons) from electroplating facilities to natural waters are:

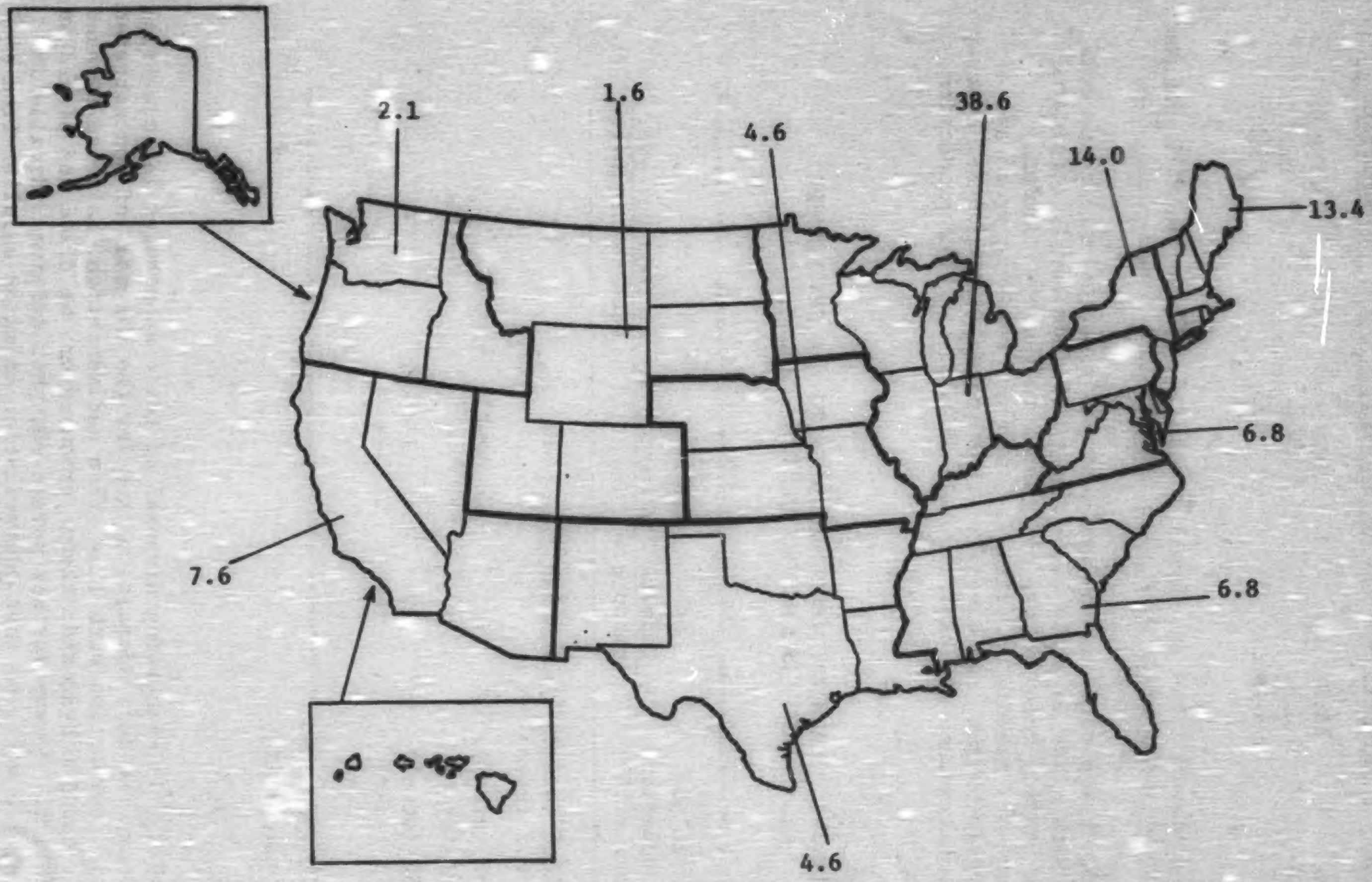
2.1
1.6
4.6
38.6
14.0
13.4
6.8
6.8
7.6
4.6

Figure 1.5. Geographical distribution of independent job platers by EPA region (percent). (Source: U.S. Environmental Protection Agency, 1975b.)

Year	Direct	Through Publicly Owned Treatment Works	To Publicly Owned Treatment Works Sludge	Concentrated Waste and Sludge to Landfill
1976	13.6	35.8	107.3	18.3
1980	1.0	3.3	10.0	160.7
1985	0.22	0.74	2.23	135.3

He forecasts a downward trend in cadmium discharge, though landfill cadmium will first increase until after 1980 when it will turn downward.

Cadmium discharge rates to the environment from steelmaking and coke production are summarized in Table 1.1. The steel industry is considered to be among the leading contributors of cadmium to the environment. Cadmium emissions are associated primarily with the refining processes (open-hearth, basic-oxygen, and electric arc furnaces) in which No. 2 scrap steel (contains galvanized and plated metal) is used and coke production.

TABLE 1.1. CADMIUM DISCHARGE RATES TO THE ENVIRONMENT FROM STEELMAKING AND COKE PRODUCTION[a]

Year	Total Production, tons x 10^6	Cadmium Discharge, metric tons per year		
		Atmosphere	Landfill	Aqueous Discharge
1975	116.8 (steel)	13	105	6
	82.2 (coke)	7	-	-
1980	152 (steel)	13	290	5
	107 (coke)	10	-	-
1985	158 (steel)	10	322	3
	111 (coke)	10	-	-

[a] Source: Yost, 1976.

Powers (1976), in discussing disposal of toxic substances in industrial wastes, claims that the only adequate method for the disposal of concentrated cadmium wastes is coagulation with lime, then sedimentation, followed by sand filtration. The cadmium hydroxide sludge produced can be dried and placed in an approved landfill. Powers further points out that cadmium hydroxide is not very soluble, 2.6 mg/ℓ, so that contamination of water supplies from a landfill operation should not be a problem, at least in an approved chemical landfill area of the California Class I type ("those at which complete protection is provided for all time for the quality of ground and surface waters from all wastes deposited therein and against hazard to public health and wildlife resources") (Fields and Lindsey, 1975).

Most processes associated with cadmium in pigments involve a high-temperature calcination treatment so air emissions are encountered, estimated at 9.5 MT by Fulkerson and Goeller (1973). While it does appear that little cadmium is lost to the environment in manufacturing of paints, the cadmium is ultimately dispersed in use by weathering and discarding of painted items. Although their use and disposal results in almost total dispersal to the environment, other major uses of cadmium (alloys, plastics manufacture, and nickel-cadmium batteries) contribute only minor quantities of cadmium to the environment in their manufacture.

Inadvertent Sources of Cadmium Release

Principal inadvertent sources of cadmium released to the environment are phosphate fertilizers, sewage sludge, and the combustion of fossil fuels. Minor sources are rubber tire wear, from the cadmium associated with zinc oxide vulcanization accelerator, as well as use and recycling of galvanized steel which already have been discussed.

Fulkerson and Goeller (1973) estimate a range of 110 to 900 metric tons of cadmium inadvertently emitted per year, corresponding to a consumption of 450 million metric tons of coal and assuming cadmium contents in the rather wide range of 0.25 to 2 ppm. Estimation of the total quantities of cadmium released is subject to considerable uncertainty as a result of the large variability in intrinsic cadmium contents of natural raw materials. Fulkerson (1975) later revised this estimate to 150 MT/yr of atmospheric emissions, based on 600 million MT/yr of coal at an average of 2.5 ppm cadmium and 90 percent precipitator efficiency. These appear to be high values for average cadmium concentrations on the basis of available coal analyses. Ruch et al. (1974) reported the results of the analyses of 101 coal samples, 82 of which were from the Illinois basin. Only about 50 percent of the samples exceeded 0.6 ppm and only 34 percent exceeded 1.2 ppm. Thus, a more realistic estimate appears to be the one developed by Sargent and Metz (1975) who estimated 80 MT/yr atmospheric emissions and 470 MT/yr in the residues and captured fly ash, on the basis of 450 million MT/yr of coal and an average 1 ppm cadmium content.

Klein et al. (1975) studied the pathways of 37 trace elements through a coal-fired plant, measuring the concentrations and mass flows in the coal, slag, fly ash, and exit gas stream. Cadmium was analyzed by isotope dilution spark source mass spectroscopy. The following ppm concentrations of cadmium were observed:

Coal - 0.47
Slag - 1.1
Precipitator inlet fly ash - 8.0
Precipitator outlet fly ash - 51.0

The increased concentration in the particles leaving the electrostatic precipitator suggests that cadmium losses will be associated with ultrafine particulate matter. Size ranges of outlet fly ash particles were not reported, although other test data indicated that they would be 0.1 to 0.5 micrometer in diameter or less. The cadmium mass balance indicated less than 2.5 percent was contained in the exit gas stream, considerably lower than the 17.5 percent assumed by Sargent and Metz (1975) in their estimation of atmospheric emissions.

A more detailed study of flow pathways of cadmium through power plants, including the flue gas desulfurization step, has recently been reported by Holland et al. (1975). Cadmium concentrations determined in the coal feed and in various streams in 5 coal-fired power plants are summarized in Table 1.2. These results provide evidence that collected cadmium is satisfactorily immobilized in flue gas scrubber sludges as indicated by the 0.5 to 2 ppb in leachate from the sludge.

Oils exhibit the same type of variability in cadmium content as does coal, so that selecting an average value for purposes of estimating emissions presents problems. Lagerwerff and Specht (1971) found 0.07 to 0.11 ppm in diesel oils and 0.42 to 0.53 ppm in heating oils. Fulkerson and Goeller (1973) assumed an average of 0.3 ppm and a 50 billion-gallon annual consumption in deriving an estimate of about 55 MT/yr emitted. The practical technology to eliminate cadmium from oils does not appear to be available, and this source of cadmium will probably continue at about its present levels.

Cadmium is found associated with the phosphate in phosphate rock, and tends to follow the phosphorus in processing, and thus is a contaminant in phosphate fertilizers. Fulkerson and Goeller (1973) assumed a range of 2 to 20 ppm and estimated an input of 23 to 230 MT/yr from commercial fertilizers. Sargent and Metz (1975), assumed a lower value of 7.8 ppm on the basis of other analyzes, and estimated cadmium input to the soil from this source of 100 metric tons in 1975.

Sewage sludge is a third significant source of inadvertent cadmium release. Fulkerson and Goeller's (1973) estimate of inadvertent releases assumed a cadmium content in sludge of 15.6 ppm, based on some Swedish data. On the basis of recent U.S. data, this appears to be low for the more industrialized wastes of this country. Salotto et al. (1974) analyzed about 100 digested sludge samples from 33 wastewater treatment plants in 13 states; they found the cadmium contents to be log-normally distributed, with a geometric mean of 43 ppm, an arithmetic mean of 75 ppm, and a median value of 31 ppm. Sargent and Metz (1975), using an assumed average cadmium content of 75 ppm, derived an estimate of 300 MT/yr from sludge. They further assumed that 60 percent is applied to land, 10 percent is dumped at sea, and 30 percent is incinerated, producing 20 metric tons of air emissions at an incinerator scrubber efficiency of 80 percent.

TABLE 1.2. CADMIUM CONCENTRATIONS FROM FIVE POWER PLANTS[a]
(in ppm)

Source	Electric Power Generating Station 1	2	3	4	5
Coal	0.028	0.05	0.30	0.11	7.9
Bottom ash	0.19	0.41	0.86	1.1	1.6
Particulate collector ash	0.39	1.4	5.3	4.2	
Lime or limestone scrubber feed	0.28	0.24	0.92	0.90	0.65
Ash pond liquor		0.0005	0.0001	0.001	0.04
Scrubber sludge	0.40			1.1	0.25
Scrubber liquor	0.006[b]			0.002[b]	0.009[b]
Make-up water for scrubber	0.0004[b]	0.0004[b]	0.0009[b]	0.001[b]	0.0007[b]
Coal ash leachate	0.001	0.0025	0.01	0.001	0.0011
Flue gas desulfurization sludge leachate	0.0005			0.001	0.002

[a] Source: Holland et al., 1975.

[b] Concentration in ppb.

Summary of Cadmium Input to the Environment

As shown in Table 1.3, Sargent and Metz (1975) estimate the current total quantity of cadmium released to the environment to be about 1,800 MT/yr. Land-destined wastes constitute a major portion of the total environmental emissions with more than 82 percent, followed by air emission at 16 percent, and waterborne effluents only a little over 1 percent. These numbers are based on limited measurements and estimates. Also included in the table are estimates provided by Yost (1976).

Of the approximately 2,000 metric tons of cadmium emitted to the environment in 1974, about 20 percent came from zinc mining and smelting; 50 percent was from fossil-fuel combustion, fertilizer use, and disposal of sewage sludge; and 30 percent was from industrial uses including remelting of cadmium-plated scrap, incineration of plastics containing cadmium, and electroplating.

Since cadmium is used primarily dissipatively, the total destined for introduction into the environment will approximately equal that produced and used. Thus, the principal problem is determining to which compartment--air, water, land--the emissions are consigned. Nevertheless, at present, it appears that the overall trend in uncontrolled emissions of cadmium to the environment are definitely down, spurred by the increasingly complete application of pollution abatement controls. This trend is expected to continue, although there will be some offset as a result of natural growth in the economy. Also, there are further opportunities for substitution of other materials for cadmium and its compounds and for further reduction of the cadmium content of commercial zinc. On the other hand, the cadmium contamination in fossil fuels and in fertilizer is only partially controllable and these two sources may set the lower bounds of attainable minimums in cadmium emissions to the environment.

TABLE 1.3. REVISED CADMIUM EMISSION ESTIMATES[a]
(Metric Tons per Year as Elemental Cadmium)

Source	Airborne Emissions	Waterborne Effluents	Land-Destined Wastes	Total Emissions
Zinc ore mining and beneficiation	0.2	-0	250	
Primary zinc industry	102	10.0 (1971-72) 2.0 (1977) 1.3 (1983)	-0	
Total: Extraction, refining, and production	102	-7.0 (1974-75) -2.0 (1980)	250	359 (1974-75) 354 (1980)
Electroplating shops	1.0	10.5 (1972) 49.4 (1976)[c] 4.0 (1977) 4.3 (1980)[c] 0 (1983) 0.96 (1985)[c]	73.5 (1972) 18.3 (1976)[c] 80.0 (1977) 160.7 (1980)[c] 0 (1983) 135.3 (1985)[c]	
Pigment manufacture	9.5[b]	0.75	16.5	
Stabilizer manufacture	2.7[b]	-0	-0	
Alloy manufacture	2.3[b]	-0	-0	
Battery manufacture	0.7[b]	0.3	8.4 (1973) 11.4 (1977) 9.1 (1983)	
Total: Industrial conversion	15.0	-8.0 (1974-75) -3.0 (1980)	-102.0 (1974-75) - 75.0 (1980)	125 (1974-75) 93 (1980)
Secondary nonferrous metals	2.2	-0	20	
Iron and steel industry	10.5	-0	330	
Steelmaking[c]	13.0 (1975) 13.0 (1980) 10.0 (1985)	6 (1975) 5 (1980) 3 (1985)	105 (1975) 290 (1980) 322 (1985)	
Coke production[c]	7.0 (1975) 10.0 (1980) 10.0 (1985)			
Galvanized products	-0	-0	40	
Rubber tire wear	5.2[b]	-0	-0	
Incineration	16.0	-0	70	
Total: Consumption and disposal of cadmium-containing products	34.0	-0	460	494
Phosphate fertilizers	-0	-0	100 (1974) 130 (1980)	
Phosphate detergents	-0	10.2	-0	
Coal combustion	80.0 (1974) 80.0 (1980)	-0 -0	370 (1974) 680 (1980)	
Diesel and fuel oil combustion	50.0[b]	-0	-0	
Lubricating oils	0.8[b]	-0	-0	
Sewage sludge	20.0	-0	250	
Total: Inadvertent sources	151.0	10.0	720 (1974-75) 1,060 (1980)	831 (1974-75) 1,221 (1980)
Grand totals	300.0	25.0 (1974-75) 15.0 (1980)	1,500 (1971-75) 1,800 (1980)	1,800 (1974-75) 2,100 (1980)

---

[a] Source: Sargent and Metz, 1975 (with additional data from Yost, 1976).
[b] Estimates unchanged from Fulkerson and Goeller (1973).
[c] Yost, 1976.

2. CADMIUM LEVELS IN THE ENVIRONMENT

Cadmium is a relatively rare element and is only a minor element in U.S. technology. When total U.S. consumption is only of the order of 5,000 MT/yr, even total dispersion would not begin to compare to the quantities of other metals, e.g., copper, lead, or zinc, entering the environment each year. While the uses of cadmium are largely dissipative, the forms in which it is utilized are fairly stable and so its dispersal is not rapid and total, as it tetraethyl lead antiknock fluid, for example. Thus, cadmium is found in the environment in ppm and ppb levels.

AIR

National Atmospheric Monitoring Program

In recent years the EPA has begun monitoring of cadmium on a national level as part of the National Air Surveillance Networks (NASN). Since 1968, the number of urban stations operating has been 164; the nonurban total is 30 (Figure 2.1) (U.S. Environmental Protection Agency, 1972). NASN also compiles and reports data collected by state and local agencies. The EPA maintains a record of most ambient air sampling performed in the U.S. on its SAROAD (Storage and Retrieval of Aerometric Data) computer system.

Due presumably to the employment of emission spectroscopy instead of atomic absorption, the atmospheric cadmium concentrations reported for 1970-1974 NASN samples (Akland, 1976) have only a small fraction of positive values which permit calculation of annual averages; for many states no detectable atmospheric cadmium concentrations are reported for this 5-year period. All urban stations with at least one reported annual average are presented in Table 2.1. Analyses of samples taken at 46 nonurban stations during the 1970-1974 period were uniformly below the limit of detection.

To appraise trends, the 50th percentile (the median) and the 90th percentile of the annual averages were chosen by Faoro and McMullen (1977) as the statistics to best describe the change in metals' concentrations over time. This minimizes the influence of individual extreme values and simplifies the characterization trends for metals having large amounts of data below the detection limit. Also, these statistics can portray different aspects of the yearly average distribution—the 50th percentile, the typical, and the 90th percentile, the high concentration site.

Figure 2.2 graphically presents the urban cadmium concentrations for the two broad emission categories (combustion and industry) in terms of the

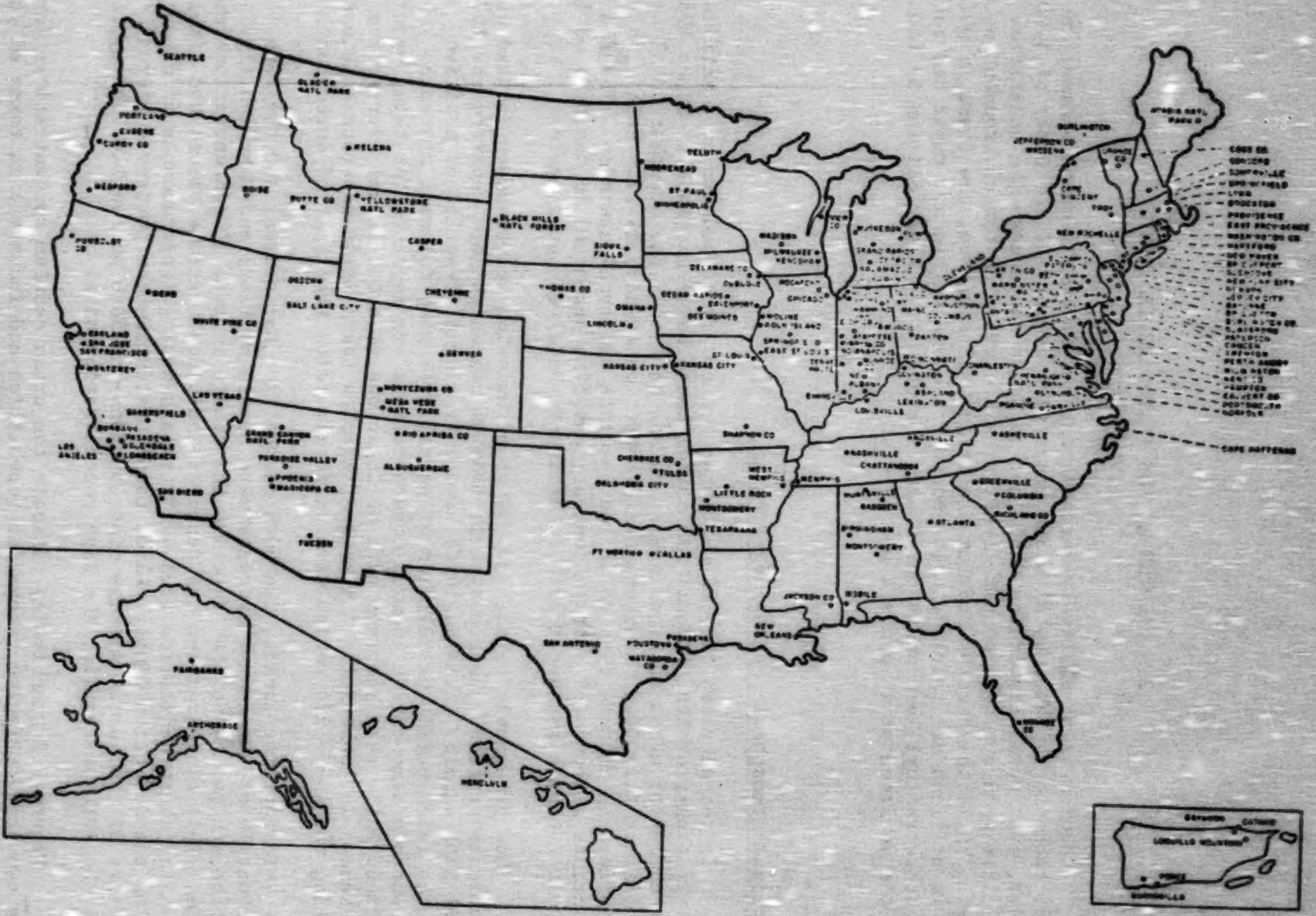
SEATTLE
PORTLAND
EUGENE
CURRY CO
MEDFORD
HUMBOLDT CO
GLACIER NATL PARK
HELENA
BOISE
BUTTE CO
YELLOWSTONE NATL PARK
CASPER
CHEYENNE
RENO
WHITE PINE CO
OGDEN
SALT LAKE CITY
DENVER
MONTEZUMA CO
MESA VERDE NATL PARK
OAKLAND
SAN JOSE
SAN FRANCISCO
MONTEREY
LAS VEGAS
BAKERSFIELD
BURBANK
PASADENA
GLENDALE
LONG BEACH
LOS ANGELES
SAN DIEGO
GRAND CANYON NATL PARK
PARADISE VALLEY
PHOENIX
MARICOPA CO.
TUCSON
RIO ARRIBA CO
ALBUQUERQUE
BLACK HILLS NATL FOREST
SIOUX FALLS
THOMAS CO
OMAHA
LINCOLN
KANSAS CITY
KANSAS CITY
DULUTH
MOORHEAD
ST PAUL
MINNEAPOLIS
DELAWARE CO
DUBUQUE
CEDAR RAPIDS
DAVENPORT
DES MOINES
MADISON
MILWAUKEE
KENOSHA
ROCKFORD
CHICAGO
MOLINE
ROCK ISLAND
SPRINGFIELD
EAST ST LOUIS
ST LOUIS
SHANNON CO
CHEROKEE CO
TULSA
OKLAHOMA CITY
WEST MEMPHIS
MEMPHIS
LITTLE ROCK
MONTGOMERY
TEXARKANA
FT WORTH
DALLAS
SAN ANTONIO
HOUSTON
PASADENA
MATAGORDA CO
NEW ORLEANS
JACKSON CO
MOBILE
MUSKEGON
GRAND RAPIDS
CLEVELAND
DAYTON
COLUMBUS
CINCINNATI
EVANSVILLE
LOUISVILLE
LEXINGTON
ASHLAND
CHARLESTON
NASHVILLE
CHATTANOOGA
ASHEVILLE
HUNTSVILLE
GADSDEN
BIRMINGHAM
MONTGOMERY
ATLANTA
GREENVILLE
COLUMBIA
RICHLAND CO
BURLINGTON
JEFFERSON CO
TROY
NEW ROCHELLE
ACADIA NATL PARK
CAPE HATTERAS
FAIRBANKS
ANCHORAGE
HONOLULU
BAYAMON
CATANO
LUQUILLO MOUNTAINS
PONCE
GUAYANILLA

Figure 2.1. Map showing NASN stations for measuring cadmium.

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TABLE 2.1. ANNUAL AVERAGE URBAN ATMOSPHERIC CADMIUM CONCENTRATIONS REPORTED BY NATIONAL AIR SURVEILLANCE NETWORKS, 1970-1974[a]
(L.D. = Limit of Detection)

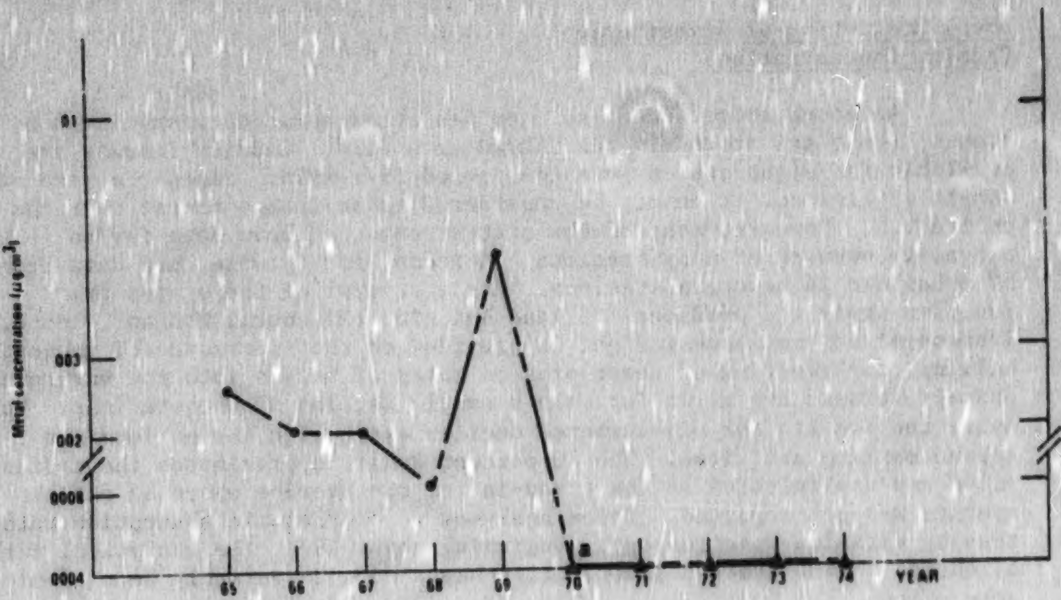
Location	Station Number	Cadmium Concentration, $\mu g/m^3$ 1970	1971	1972	1973	1974
Arizona						
Douglas	01			0.0132		
Tucson	01	0.0065	0.0251	0.0045[b]	0.0045[b]	0.0062[b]
Colorado						
Denver	01	0.0102	0.0101			
Connecticut						
Bridgport	01	0.0117		0.0057		
Waterbury	01	0.0251	0.0048	0.0174	0.0027[b]	0.0139
Georgia						
Atlanta	01		0.0210			
Illinois						
Chicago	01	L.D.	0.0065	0.0030[b]		
East St. Louis	01		0.0045[b]	0.0052		
Peoria	01	0.0067				
Indiana						
East Chicago	01	0.0187	0.008[b]			0.0056
Indianapolis		0.0066	0.0063	0.009[b]		
Kentucky						
Ashland	02	0.0108		0.0093		0.006[b]
Covington	01	0.0048[b]	0.0049	0.003[b]		L.D.
Louisiana						
New Orleans	02	L.D.	0.0184	L.D.		
Shreveport	01	L.D.	0.0132	L.D.		L.D.
Maine						
Portland	02	L.D.	0.0086			
Michigan						
Detroit	01	0.0047	L.D.			
Grand Rapids	01		0.0116	L.D.		
Minnesota						
St. Paul	01	0.0060		0.0086		
Missouri						
St. Louis	01		0.0155			
Montana						
Helena	01		0.0150			

TABLE 2.1. (Continued)

Location	Station Number	Cadmium Concentration, $\mu g/m^3$				
		1970	1971	1972	1973	1974
New Jersey						
Camden	01	0.0063				
Elizabeth	02		0.0167			
Jersey City	01	0.0081	0.0056	0.0124		
Newark	01	0.0125		0.0159		0.0052
Perth Amboy	01	0.0055[b]	0.0128	0.0189		
New York						
New York City	01	0.0071		0.0060		
North Carolina						
Winston Salem	02		0.0076			
Ohio						
Cincinnati	01	0.0086				
Cleveland	01	0.0088				
Youngstown	01	0.0056				
Pennsylvania						
Allentown	01	0.0081	0.0042[b]	0.0178	0.0042[b]	0.0134
Bethlehem	02	0.0140	0.0191	0.0068[b]	0.0068	
Hazleton	01				0.0065	
Philadelphia	04			0.0057		0.0038[b]
Scranton	01	L.D	0.0067	L.D.		L.D.
Texas						
El Paso	02	0.0618		0.0442	0.0206	0.0242
Virginia						
Lynchburg	01	0.0135	0.0040[b]	L.D.		
Wisconsin						
Kenosha	01		L.D.	0.0143		
Racine	01	L.D.		0.0071		

[a] Source: Akland, 1976.

[b] L.D./2 used for computation of annual average.



[a] ▲ indicates value below lower discrimination limit.

Figure 2.2. Trends in 50th percentile of annual averages for cadmium associated with metal industry sources at urban sites (Faoro and McMullen, 1977).

50th percentile of annual averages. The 90th percentile plots are not shown since they provided very similar results. Cadmium shows a sharp downward trend, 1969-1970, and for the period 1970-1974, the reported cadmium metal concentrations were below the lower discrimination limit (Faoro and McMullen, 1977).

Local Monitoring of Atmospheric Cadmium Concentrations

As noted above, EPA also compiles atmospheric data submitted by states; these are stored in the SAROAD data file. Cadmium results are available for eight states over the period 1971-1976. Since the size of sample is limited, it cannot be considered to delineate trends over the entire U.S. However, most of the states reporting have data for an extensive network of many stations. Arizona, for example, has data from 53 urban and 14 nonurban stations. Also, several of the states are included among the producers of lead and zinc (Missouri, Montana, Idaho, Tennessee) so that some insight is provided on the importance of mining, milling, and smelting of these ores on entry of metals into the environment. Annual averages are given for only a small fraction of the stations. However, the results for odd-numbered deciles along with the maximum and second maximum are given. The 50 percent decile approximates the median value and was selected as the stand-in for the average where an annual average was not reported. These analyses were by atomic absorption rather than by emission spectroscopy. Beginning about 1970, the analytical method of choice of the states' laboratories has almost universally been atomic absorption.

The SAROAD 50 percent decile results for these eight states are tabulated in Tables 2.2 (urban) and 2.3 (nonurban). Unlike the NASN emission spectroscopic analyses, positive values were the rule and ND entries were absent, even for nonurban areas. In areas remote from cadmium sources, concentrations as low as 0.0001 to 0.0005 $\mu g/m^3$ were measured.

The midwestern section of the country has been the subject of several atmospheric monitoring studies of trace metals. A study was conducted during a 2-day period in 1972 in Chicago, Illinois (Harrison, 1973). Atomic absorption spectroscopy was the analytical method used for this investigation. With these data it was possible to plot isopleths, as shown in Figures 2.2 and 2.4. The November 5, 1972, data, Figure 2.3, show a maximum concentration of 0.0083 $\mu g/m^3$ on the north side of Chicago, in an area free of point sources to which the high concentration could be attributed. On November 23, 1972, the area of maximum concentration, 0.0073 $\mu g/m^3$, was located some miles to the west, and concentration at the north side area had decreased to 0.002 $\mu g/m^3$. From these data, it is evident that mesoscale meteorological factors were dominant in determining atmospheric cadmium distribution. However, given adequate mesoscale meteorological data, it appears that with some refinements the approach could be used to identify and locate point sources.

TABLE 2.2. ATMOSPHERIC CADMIUM CONCENTRATIONS FOR URBAN SAMPLING STATIONS IN EIGHT STATES, 1971-1976

Location	Station Number	Cadmium Concentration, μg/m^{3b,c}					
		1971	1972	1973	1974	1975	1976
Arizona							
Ajo	01	0.0001	0.002	0.0001	0.001		
Casa Grande	01				0.003		
Chandler	01			0.003	0.0021^d	0.0001	
Claypool	01	0.0001	0.007	0.0001			
Clifton	03	0.0001	0.005	0.003	0.006		
Cochise County	01	0.119	0.012				
Cochise County	02	0.008	0.002				
Cochise County	04			0.01	0.006		
Flagstaff	01	0.0001	0.0001	0.001	0.001		
Gila County	01			0.009	0.01		
Glendale	01				0.0001	0.0001	
Greenlee County	91				0.028		
Kingman	01			0.003	0.001		
Maricopa County	09				0.0001	0.0001	
Mesa	02				0.0008^d	0.001^d	
Mohave County	06	0.0001	0.001	0.0001	0.0001		
Mohave County	01			0.003	0.002		
Navajo County	02	0.0001	0.002				
Navajo County	07				0.0001		
Nogales	02			0.003	0.003		
Paradise Valley	01			0.002	0.001^d		
Paradise Valley	02			0.005	0.0039^d	0.0001	
Phoenix	02		0.001	0.0018^d	0.0019^d	0.0008^d	
Phoenix	04		0.003	0.0036^d	0.0023^d	0.0008^d	
Phoenix	05		0.001	0.0017^d	0.001		
Phoenix	06		0.004	0.0035^d	0.0001		
Phoenix	08		0.004				
Phoenix	09			0.0001			
Phoenix	10			0.002	0.0015^d	0.003	
Phoenix	11			0.003	0.0059^d	0.004	
Phoenix	13				0.0001	0.0004^d	
Phoenix	14				0.001		
Pima County	11					0.0001	
Pinal County	01	0.016	0.002	0.003	0.0001		
Pinal County	02			0.005			
Pinal County	03			0.002	0.005		
Prescott	01			0.001	0.0001		
Scottsdale	01		0.004	0.003			
Scottsdale	02			0.003	0.0001		
Scottsdale	03				0.0001	0.0003^d	
Scottsdale					0.0001	0.0006^d	
Sierra Vista	01				0.001		
Sierra Vista	02				0.003		
South Tucson	01					0.0001	
Sun City	02			0.006	0.0071^d	0.0001	
Superior	03	0.006	0.001	0.002	0.003		
Tucson	02					0.0001	
Tucson	07					0.0001	
Tucson	08					0.0001	
Tucson	12					0.0001	
Tucson	13					0.0001	
Yavapai County	01	0.0016	0.0001	0.001	0.001		
Yuma	02	0.0001	0.0001	0.001	0.001		
Idaho							
Kellogg	04				0.3	0.0963^d	
Kellogg	06				0.24	0.1189^d	
Kellogg	07				0.222	0.126	
Kellogg	08				0.252	0.122	
Kellogg	09				0.489	0.247	
Kellogg	10				0.199	0.104	
Shoshone County	04				0.16	0.1287^d	

TABLE 2.2. (Continued)

Location	Station Number	Cadmium Concentration, μg/m^3[b,c]					
		1971	1972	1973	1974	1975	1976
Idaho							
Shoshone County	16				0.07	0.0154[d]	
Shoshone County	17				0.08	0.0574[d]	
Shoshone County	18				0.03	0.0095[d]	
Shoshone County	19				0.06	0.0293[d]	
Shoshone County	20				0.12	0.0346[d]	
Shoshone County	21				0.37	0.2489[d]	
Shoshone County	22				0.174	0.137	
Shoshone County	23				0.125	0.071	
Shoshone County	24				0.146	0.108	
Shoshone County	25				0.095	0.073	
Minnesota							
Anoka	01		0.003				
Austin	01		0.001	0.001	0.001	0.001	
Bemidji	01		0.001				
Bemidji	02		0.001	0.001	0.001	0.001	
Bloomington	04		0.001	0.002	0.001	0.001	
Brainerd	01		0.001	0.002	0.001	0.001	
Carlton County	01			0.001	0.001		
Cloquet	11				0.001	0.001	
Dakota County	07		0.001				
Dakota County	20		0.007	0.010	0.001	0.001	
Dakota County	21			0.001	0.001		
Duluth	02		0.001	0.001	0.001	0.001	
Duluth	03		0.001	0.001	0.001	0.001	
Duluth	04		0.001	0.001	0.001	0.001	
Duluth	05		0.001	0.001	0.001	0.001	
Duluth	06		0.001	0.003	0.002	0.001	
Duluth	13		0.001	0.002	0.001	0.001	
Duluth	13				0.001	0.001	
Duluth	15			0.004	0.003	0.001	
Duluth	17					0.001	
East Grand Forks	03		0.001	0.001	0.001	0.001	
Ely	01			0.001	0.001	0.001	
Fairbault	01		0.001	0.004			
Fergus Falls	01		0.001	0.001	0.001	0.001	
Fergus Falls	10		0.001	0.008			
Grand Rapids	03			0.001	0.001	0.001	
Hastings	05		0.001	0.004	0.002	0.003	
Hibbing	01		0.001	0.003	0.002	0.002	
Hoyt Lakes	01		0.001	0.004	0.001	0.001	
Hutchinson	01		0.003	0.001	0.001	0.001	
International Falls	01		0.001	0.020			
International Falls	02			0.006	0.001	0.001	
International Falls	03					0.002	
International Falls	05					0.001	
Itasca County	01		0.001	0.010			
Itasca County	02			0.001			
Mankato	01		0.001	0.001	0.001	0.001	
Marshall	01		0.001	0.001	0.001	0.001	
Minneapolis	05		0.001	0.004	0.001	0.001	
Minneapolis	07		0.001	0.002	0.001	0.002	
Minneapolis	14			0.001	0.001	0.001	
Minneapolis	20		0.001	0.002	0.002	0.001	
Minneapolis	22		0.004	0.002	0.001	0.002	
Minneapolis	27		0.001	0.006	0.002	0.003	
Minneapolis	31		0.001				
Minneapolis	32				0.002	0.002	
Moorhead	03		0.001	0.014			
Moorhead	04		0.001	0.001		0.001	
Moorhead	05		0.001	0.001	0.001	0.001	
Ortonville	01		0.001	0.001	0.001	0.001	

TABLE 2.2. (Continued)

Location	Station Number	Cadmium Concentration, μg/m^3[b,c]					
		1971	1972	1973	1974	1975	1976
Minnesota							
Red Wing	02			0.003	0.001	0.001	
Red Wing	03					0.004	
Rochester	01		0.001	0.001	0.001	0.001	
Rochester	10		0.005	0.001	0.002	0.008	
Rochester	14		0.002	0.001	0.001	0.001	
Rochester	15		0.001	0.001	0.001	0.002	
Rochester	16		0.003	0.001	0.001	0.003	
St. Cloud	01		0.001	0.001	0.001		
St. Cloud	16		0.004	0.006			
St. Cloud	17		0.008	0.011	0.008	0.004	
St. Cloud	21				0.001	0.001	
St. Louis County	01		0.001	0.002	0.002	0.002	
St. Louis County	03		0.001	0.001	0.001	0.001	
St. Louis Park	06		0.003	0.001	0.004	0.001	
St. Paul	01		0.001	0.005	0.003		
St. Paul	03		0.001	0.002	0.001	0.001	
St. Paul	13		0.001	0.002	0.001		
St. Paul	14		0.002	0.006	0.001	0.001	
St. Paul	16		0.001	0.002	0.001	0.001	
St. Paul	18		0.012	0.004	0.009	0.006	
St. Paul	21		0.003	0.006	0.006	0.002	
St. Paul	23		0.001	0.003	0.001	0.002	
St. Paul	24		0.001	0.001	0.001	0.001	
St. Paul	30			0.001	0.002	0.002	
St. Paul	31				0.001	0.002	
St. Paul	32				0.001		
St. Paul Park	04		0.004	0.004	0.001	0.002	
Shakopee	02				0.001	0.001	
Silver Bay	08		0.0001	0.001			
Silver Bay	09		0.001	0.001			
Silver Bay	10		0.0001	0.001			
Silver Bay	11		0.001	0.002			
Silver Bay	12		0.002	0.001			
Silver Bay	13			0.001			
Stearns County	01		0.001	0.007	0.004	0.001	
Stearns County	02		0.001	0.006	0.003	0.004	
Stearns County	03		0.006	0.007	0.003	0.001	
Stillwater	02			0.001	0.001	0.001	
Virginia	01		0.001	0.001	0.001	0.001	
Waite Park	01		0.002				
Wayzata	02			0.001	0.001	0.001	
Wayzata	03		0.001	0.005			
Willmar	01		0.001	0.001	0.001	0.001	
Winoma	02		0.001	0.001			
Winoma	09			0.003	0.002	0.001	
Winoma County	01		0.001	0.001			
Worthington	01		0.001	0.001	0.001	0.001	
Missouri							
Camden County	01					0.001	
Cape Girardeau	02					0.0034	
Chillicothe	01					0.002	
Columbia	02					0.0032	
Columbia	03					0.0035	
Fulton	01					0.005	
Hannibal	02					0.0039	
Jefferson City	02					0.002	
Jefferson County	0505					0.11	
Joplin	01					0.004	
Kirksville	01					0.003	
Maryville	01					0.003	
Mexico	01					0.004	

TABLE 2.2. (Continued)

Location	Station Number	Cadmium Concentration, μg/m^{3}[b,c]					
		1971	1972	1973	1974	1975	1976
Missouri							
Mexico	04					0.0044	
New Madrid	01					0.0018	
North Kansas City	04					0.0037	
Platte County	01					0.002	
Poplar Bluff	02					0.004	
Rolla	01					0.002	
St. Joseph	02					0.0059	
St. Joseph	03					0.0047	
Sedalia	05					0.0065	
Sikeston	02					0.0026	
Montana							
Anaconda	05	0.0301[d]	0.003				
Anaconda	06		0.013				
Billings	05	0.001					
Billings	08	0.0001					
Butte	01	0.017	0.009				
Butte	02	0.0221[d]	0.013				
Butte	03	0.01	0.003				
Butte	04	0.019					
Butte	05	0.012	0.014				
Butte	06	0.0176[d]	0.1500				
Butte	07	0.023					
Butte	10		0.017				
Cascade County	16	0.0001	0.002				
Columbia Falls	02		0.002				
Deer Lodge	01	0.008	0.009				
Deer Lodge	02	0.002					
Deer Lodge County	01	0.046					
Deer Lodge County	21	0.017					
Great Falls	07		0.002				
Hardin	01		0.001				
Kelispell	02		0.0020				
Lewis and Clark	06		0.0720				
Libby	01		0.0010				
Miles City	01		0.0001				
Powder River County	06		0.0001				
Rosebud County	21		0.0010				
Sanders County	01		0.0020				
Silver Bow County	07	0.0660	0.0770				
Oklahoma							
Ada	243	0.0070					
Bartlesville	216			0.0060	0.0028		
Bethany	14			0.0005	0.0005	0.0005	0.0005
Blackwell	591	0.0040					
Blackwell	548	0.0140					
Blackwell	549			0.0130	0.0025		
Edmond	16				0.0001		
Edmond	16			0.0005	0.0005	0.0005	0.0005
Midwest City	06			0.0005	0.0005	0.0005	0.0024
Midwest City	10			0.0005	0.0005	0.0005	0.0005
Oklahoma City	01				0.0001		
Oklahoma City	01			0.0005	0.0005	0.0005	
Oklahoma City	15			0.0005	0.0001		
Oklahoma City	15			0.0005	0.0005	0.0005	
Oklahoma City	17				0.0030		
Oklahoma City	17			0.0020	0.0024	0.0005	
Oklahoma City	18				0.0030		
Oklahoma City				0.0005	0.0020	0.0005	0.0005
Oklahoma City	21				0.0001		

TABLE 2.2. (Continued)

Location	Station Number	Cadmium Concentration, µg/m^{3} [b,c] 1971	1972	1973	1974	1975	1976
Oklahoma							
Oklahoma City	21			0.0005	0.0005	0.0005	
Oklahoma City	22				0.0001		
Oklahoma City	22			0.0005	0.0005	0.0005	
Oklahoma City	24				0.0005	0.0005	0.0005
Oklahoma County	05				0.0001		
Oklahoma County	05			0.0005	0.0005	0.0005	0.0005
Ponce City	595	0.0250					
Pryor	180	0.0040					
Sapulpa	143			0.003			
Sapulpa	143			0.0001	0.0001		
Tennessee							
Columbia	02			0.0020	0.0020	0.0020	
Kingsport	01					0.0020	
Kingsport	06					0.0020	
Marion County	01			0.0020	0.0020	0.0020	
Morristown	02			0.0020	0.0020	0.0020	
Polk County	01			0.0020	0.0020	0.0020	
Rockwood	02			0.0020	0.0020	0.0020	
Tullahoma	01			0.0020	0.0020	0.0020	
Tullahoma	02			0.0020	0.0020	0.0020	

[a] Source: U.S. Environmental Protection Agency SAROAD File, Durham, North Carolina.

[b] Determined by atomic absorption on low-temperature ashed samples.

[c] 50 percent decile value, except as noted.

[d] Annual average.

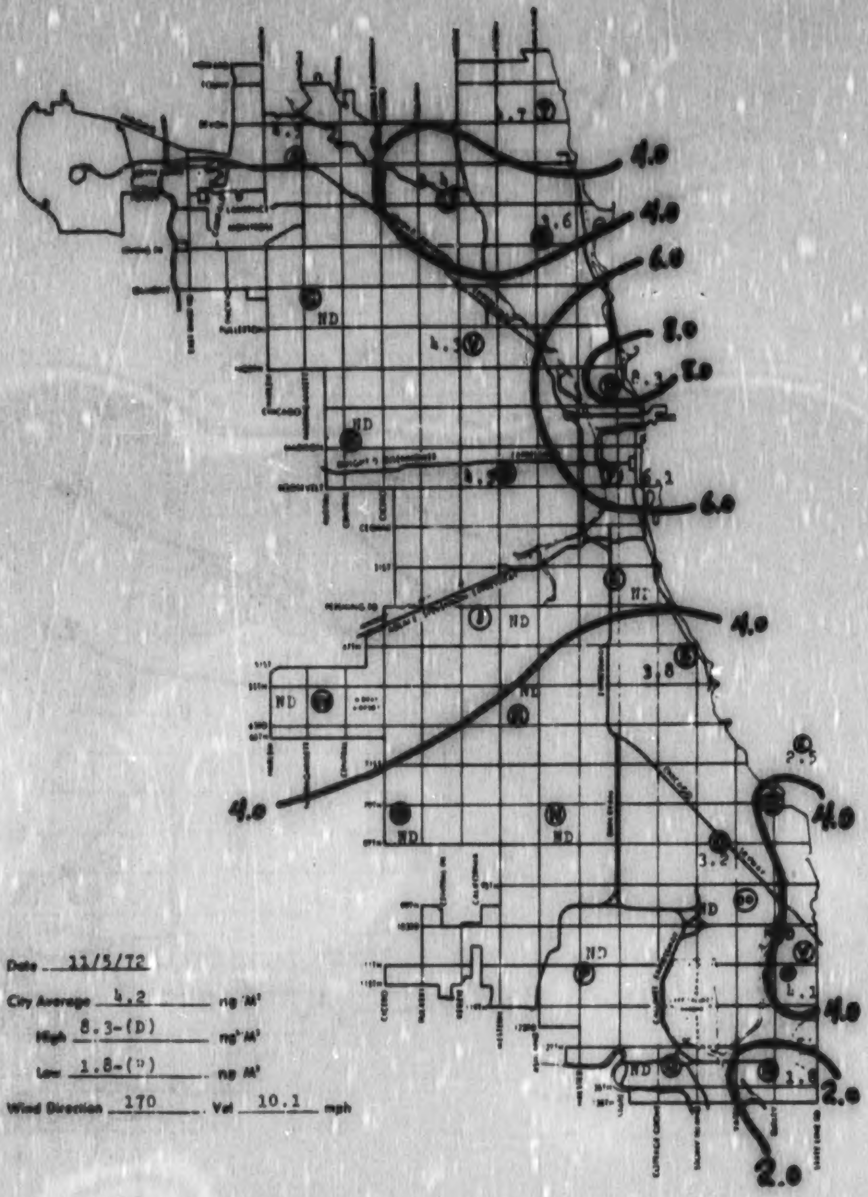
TABLE 2.3. ATMOSPHERIC CADMIUM CONCENTRATIONS FOR NONURBAN SAMPLING STATIONS IN EIGHT STATES, 1971-1976[a]

Station	Section Number	Cadmium Concentration, µg/m^{3}[b]					
		1971	1972	1973	1974	1975	1976
Arizona							
Coconino County	02	0.0001	0.001				
Coconino County	03	0.0001	0.001				
Coconino County	04		0.0001	0.001	0.001		
Kavapai County	02	0.0001	0.001	0.0001	0.001		
Gila County	03				0.003		
Maricopa County	03		0.003	0.0029^{c}	0.001		
Maricopa County	06			0.001	0.0005^{c}	0.0006^{c}	
Maricopa County	07			0.0001	0.0016^{c}	0.0006^{c}	
Maricopa County	08			0.0001	0.0045^{c}	0.004^{c}	
Navajo County	01	0.0001	0.001				
Pima County	05	0.0001	0.001	0.0001	0.001		
Pima County	09			0.006	0.001		
Pima County	10				0.002		
Winslow	01		0.0001	0.001	0.002		
Minnesota							
Lake County	01		0.0020	0.0020			
Stearns County	04			0.0060	0.0020	0.0030	
Montana							
Beaverhead County	02			0.001			
Big Horn County	08		0.0001				
Billings	07	0.0001					
Deer Lodge County	03		0.02				
Deer Lodge County	22	0.018					
Jefferson County	04	0.032					
Rosebud County	09		0.0001	0.0001			
Rosebud County	24			0.0010	0.0001		
Oklahoma							
Oklahoma City	02				0.0001		
Oklahoma City	02			0.0019	0.0005	0.0005	0.0005
Oklahoma City	19			0.0005	0.0005	0.0005	0.0005
Oklahoma City	20				0.0001		
Oklahoma City	20			0.0005	0.0005	0.0005	0.0005
Ottawa County	25				0.0001		

[a] Source: U.S. Environmental Protection Agency SAROAD File, Durnham, N.C.

[b] Determined by atmoic absorption on low-temperature ashed samples; 50 percent decile value, except as noted.

[c] Annual average.


4.0
4.0
6.0
2.0
2.0
6.0
4.0
4.0
4.0
4.0
2.0
2.0
3.6
ND
4.3
ND
ND
3.8
ND
ND
ND
ND
3.2
ND
ND
ND

Date 11/5/72

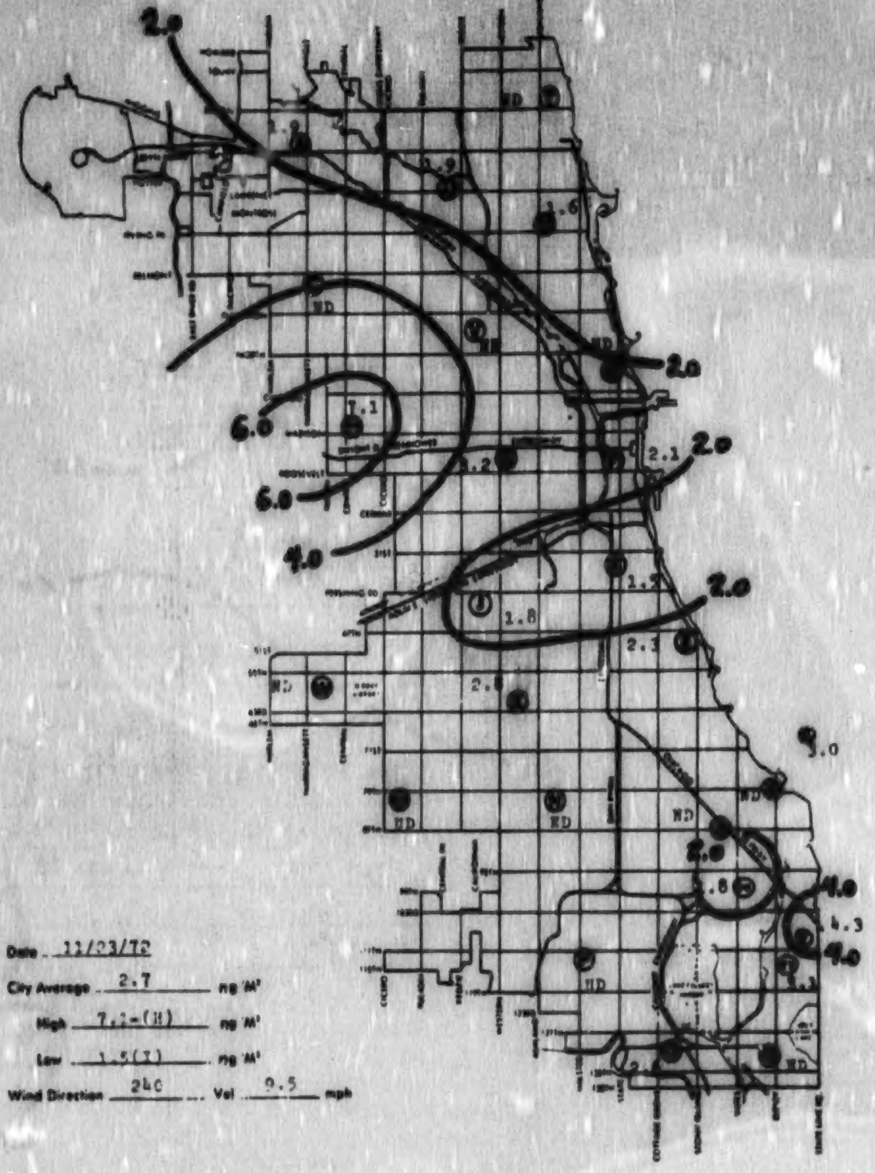
City Average 4.2 ng/M³

High 8.3-(D) ng/M³

Low 1.8-(") ng/M³

Wind Direction 170 Vel 10.1 mph

Figure 2.3. Ambient atmospheric cadmium concentrations, Chicago, Illinois, November 5, 1972 [Reprinted from Advances in Experimental Medicine and Biology, Volume 40 (Sanat K. Dhar, Editor) by P. R. Harrison, by permission of Plenum Publishing Company. Published 1973.]


2.0
2.0
2.0
2.0
6.0
6.0
4.0
4.0
4.0
2.0
7.1
1.9
1.6
2.1
1.9
1.8
2.3
4.3
ND

Date 11/23/72

City Average 2.7 ng/M^3

High 7.1-(H) ng/M^3

Low 1.5(I) ng/M^3

Wind Direction 240 Vel 9.5 mph

Figure 2.4. Ambient atmospheric cadmium concentrations, Chicago, Illinois, November 23, 1972 [Reprinted from Advances in Experimental Medicine and Biology, Volume 40 (Sanat K. Dhar, Editor) by P. R. Harrison, by permission of Plenum Publishing Company. Published 1973.].

As a part of a broad-scale investigation for the National Science Foundation (NSF) examining the environmental flow of cadmium and other trace metals, Yost et al. (1975) have studied northwestern Indiana and the metropolitan Chicago area in considerable detail. A statistical study of Chicago atmospheric dust concentrations (TSP) and meteorological data including wind speeds and precipitation led to the conclusion that the generally overlooked phenomenon of reflotation of dust appeared to account for approximately 20 percent of the annual TSP value in Chicago, and that daily values of TSP may be increased by as much as 40 to 50 percent due to winds and traffic on a dry day. The possibility of reducing TSP by street sweeping and washing was suggested. Although no such specific conclusion was drawn, it is inferred that urban Chicago atmospheric cadmium concentrations could be similarly reduced.

Trends in Cadmium Atmospheric Concentrations

Cadmium concentrations in the atmosphere of the U.S. are, with very few exceptions, of the order of a few hundredths or thousandths of micrograms per cubic meter of air. Principal exceptions to the above generalization are found in a few areas where zinc or lead mining and smelting is or has been conducted. The most notable exceptions are in Idaho and Montana, as evidenced by the 1971-1976 state data (Tables 2.2 and 2.3). Both median values and annual averages exceeding 0.1 $\mu g/m^3$ of cadmium were reported for Kellogg, Idaho, and the surrounding Shoshone County for 1974 and 1975. Kellogg is the site of a lead smelter; and an electrolytic zinc plant, which is one of the principal producers of primary cadmium metal, is located in nearby Wallace, Idaho. Data prior to 1974 are not available for these stations, so long-term trends are indeterminate, although 1975 values are, without exception, below the corresponding values for 1974 (Table 2.2).

The Butte (Jefferson County)-Anaconda (Deer Lodge County)-Helena (Lewis and Clark counties) triangle in Montana is a center of copper and lead mining, smelting and refining, and this is reflected in the atmospheric cadmium concentrations reported for this area (Tables 2.2 and 2.3). Although lower than in the Wallace-Kellogg area, they are as much as an order of magnitude higher than average U.S. cadmium concentrations.

Jefferson County, Missouri, is the site of a lead smelter, Herculaneum, and the highest median concentrations of cadmium, 0.100 $\mu g/m^3$, in the 1975 tabulation is in this county (Table 2.2).

An information resource which has to date been overlooked or neglected is the filters from the numerous local monitoring programs which are conducted by various state and local agencies. Many of these are routinely collected and stored in state agency headquarters. As a result of staff and funding problems, many of these filters are stored for long periods before analysis, which frequently consists only of particulate determination. These filters, if they have been carefully handled and stored, could supply a large mass of data on heavy metal concentrations if analyzed. Now that atomic absorption spectrometry (AAS) is so universally available and so utilitarian, the retrieval of this information from old filters is a practical possibility. Consequently, some of the gaps in atmospheric cadmium data for prior years could be filled in by the adoption of this scheme.

The uncertainties in the NASN data, the changing analytical procedures, the lack of sufficient series of comparable continuous data, and the generally barely detectable cadmium concentrations preclude the identification of definite quantitative trends in ambient atmospheric cadmium concentrations.

A definite downward trend is apparent for atmospheric cadmium concentrations associated with metal industry sources at urban sites (Figure 2.2) (Faoro and McMullen, 1977). With the exception of an unexplained increase in 1969, the concentrations declined from 1965 through 1970. For the period 1970-1974, the concentrations were below the lower discrimination limit. Possible causes given by Faoro and McMullen for this downward trend are reduced particulate emissions from metals industries and improved incineration and waste-burning practices.

No apparent trends are evident in the eight-state data, in spite of the precision of the analytical procedure used. Part of the difficulty in assessing these preliminary results arises from the fact that most of the tabulated data are 50 percent decile values, since averages were computed in only a few cases. These median values were generally lower than arithmetic averages, where both were reported, and more closely approximated than the geometric means. Although the decile values cannot be summed and averaged, it is evident by inspection that the median value of these data, smelting areas expected, is approximately µg/m^3. Whether this truly represents a decreasing trend from past years is obscured by the lack of analyses of comparable accuracy for previous years.

WATER AND SEDIMENT

National Monitoring Programs

In the autumn of 1970, a nationwide reconnaissance of selected minor elements in the surface waters of the 50 states and Puerto Rico was conducted by the U.S. Geological Survey in cooperation with the U.S. Fish and Wildlife Service (Durum et al., 1971). More than 720 samples were analyzed for arsenic, cadmium, chromium, cobalt, lead, mercury, and zinc. Samples were taken from three sources: (1) benchmark stations (located in headwaters of tributary streams); (2) surface water sources for cities greater than 100,000 pouplation (or largest city in state); and (3) water courses downstream of major municipal and/or industrial complexes. Samples were filtered through a 0.45-micron filter and were acidified when collected to stabilize the trace pollutants present. Thus, results reported are for dissolved metal only and provide no information on total concentrations present. Such results may be low, since cadmium tends to be associated with the particulate matter. The detection limit given for cadmium was less than 1 ppb by AAS.

The benchmark station analyses have been abstracted from these results and are presented in Figure 2.5 grouped by drainage basin. Of the 49 benchmark station samples analyzed, cadmium was detected in only 24 (49 percent). In none was the 10 ppb U.S. Public Health Service limit for potable water exceeded. There were some differences in basins. Even though the benchmark stations were presumably near headwaters and above sources of man-made pollution, the more industrialized areas and the down-gradient areas had the higher cadmium levels. Highest values were found in the Lower Mississippi River Basin(7), the Ohio River Basin(3), and the North Atlantic Basin(1).

Cadmium was detected in 42 percent of the total group of 720 samples in concentrations ranging from 1 to 10 ppb. This included not only the benchmark stations but also several hundred public water supplies and industrial complex samples. The regional distribution of percentages of water samples containing detectable cadmium concentrations has been presented in a subsequent paper by Durum (1974), and is illustrated by Figure 2.6 and summarized as follows:

	Maximum, ppb	Minimum, ppb	Median, ppb	<1 ppb, %	>1 ppb, %
New England and northeast	32	<1	2	36	64
Southeastern	90	<1	<1	55	45
Central	40	<1	<1	55	45
Southwestern	130	<1	<1	65	35
Northwestern	21	<1	<1	78	22

The association of detectable correlation of cadmium concentrations with regions of higher population density is evident upon comparing the New England and northeastern area, 64 percent, with the Northwestern area, 22 percent. About 4 percent of the river samples had cadmium in excess of the 10 ppb Public Health Service limit for drinking water, and these occurred in about one-third of the states. The maximum concentration found was 130 ppb, near Ray, Arizona, evidently near a highly mineralized area, since the same sample had 42,000 ppb of zinc and 4,500 ppb of cobalt.

The USGS maintains a computerized data bank for six toxic substances, cadmium, lead, mercury, PCB's, Silvex, and Toxaphene, in water and stream sediments. A summary of these data was submitted by the USGS to the Committee on Merchant Marine and Fisheries, U.S. House of Representatives (Pickering, 1976). The data for cadmium in surface waters (streams, lakes, reservoirs) and in groundwaters (wells and springs) have been extracted from this summary and are presented in Tables 2.4 and 2.5, and summarized in Table 2.6.

Dissolved values shown are based on the analyses of water passed through a 0.45 micrometer filter; "total" values are for unfiltered samples containing suspended sediment. Dissolved values are compared with the 10 ppb maximum cadmium level contained in the National Interim Primary Drinking Water Regulations (U.S. Environmental Protection Agency, 1975a). For "total" values the comparison is with the 30 ppb criterion recommended in Water Quality Criteria 1972 for freshwater aquatic life and wildlife (Rooney,

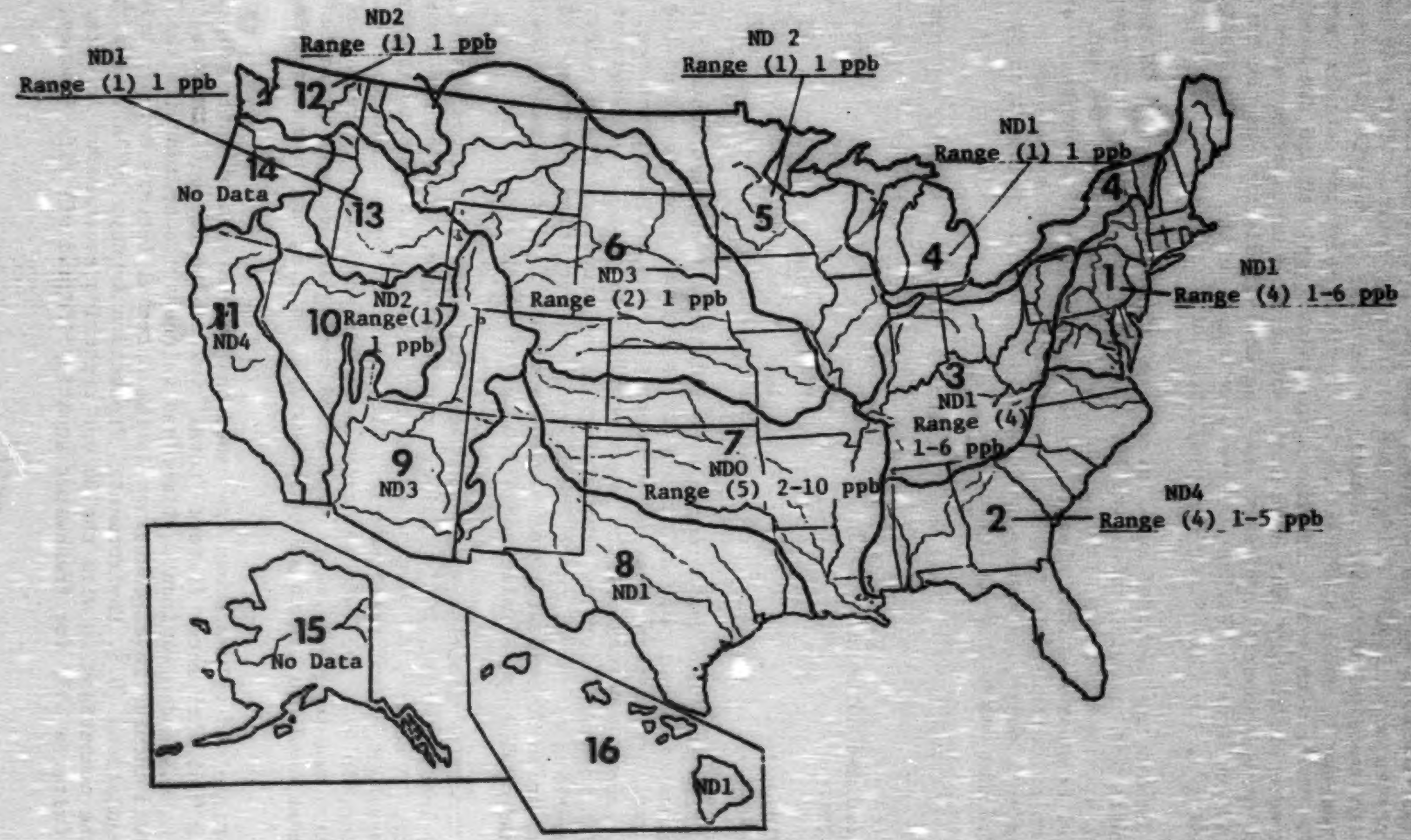

ND2
Range (1) 1 ppb
ND1
Range (1) 1 ppb
ND 2
Range (1) 1 ppb
ND1
Range (1) 1 ppb
12
14
No Data
13
5
4
4
1
ND1
Range (4) 1-6 ppb
6
ND3
Range (2) 1 ppb
11
ND4
10
ND2
Range(1)
1 ppb
3
ND1
Range (4)
1-6 ppb
7
ND0
Range (5) 2-10 ppb
9
ND3
2
ND4
Range (4) 1-5 ppb
8
ND1
15
No Data
16
ND1

Figure 2.5. Cadmium concentrations in surface waters at USGS benchmark stations in 1970 (Durum et al., 1971).

ND = Not detected. The number following ND is the number of stations.
( ) = Number of stations with detectable cadmium concentrations.

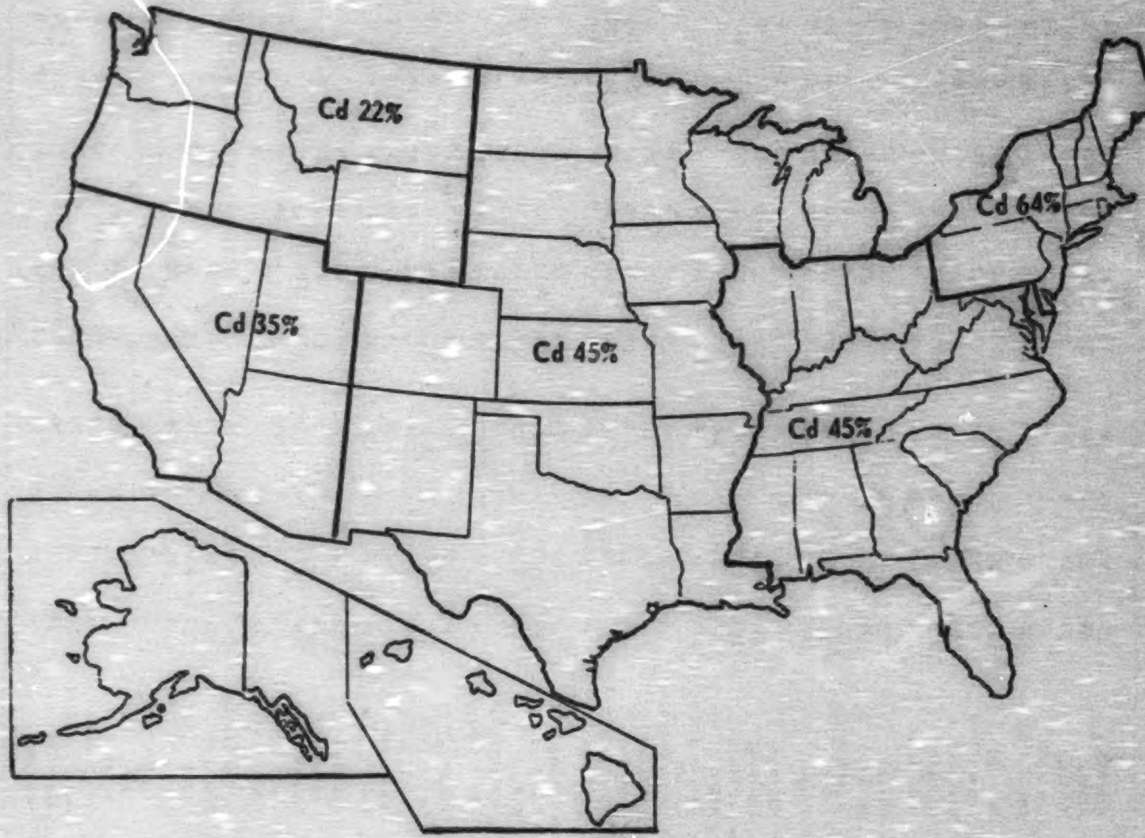

Cd 22%
Cd 64%
Cd 35%
Cd 45%
Cd 45%

Figure 2.6. Percent of river water samples containing cadmium >1 ppb in five U.S. regions (Durum, 1974).

TABLE 2.4. CADMIUM LEVELS IN SURFACE WATERS OF THE UNITED STATES[a,b]

	Dissolved Cadmium (Filtered Sample)				Total Cadmium (Unfiltered Sample)				Cadmium in Bottom Material		
State	N	N >0	N >10 ppb	Max, ppb	N	N >0	N >30 ppb	Max, ppb	N	N >0	Max, ppb
Alabama	97	90	14	90	34	32	0	10	5	4	10
Alaska	69	26	1	140	51	34	2	360	0	0	
Arizona	21	15	0	10	12	12	0	20	1	1	1
Arkansas	37	29	1	14	128	118	3	111	13	12	10
California	154	78	3	340	118	83	20	80	26	22	10
Colorado	495	221	47	910	197	190	53	960	0	0	
Connecticut	63	50	32	78	2	2	0	10	38	22	9
Delaware	10	10	0	2	0	0	0		0	0	
Florida	280	105	2	13	293	210	1	35	52	52	20
Georgia	136	68	0	5	9	7	0	5	11	11	20
Hawaii	9	5	0	2	48	12	0	10	3	1	1
Idaho	76	57	11	1,400	39	39	5	440	1	0	0
Illinois	26	16	4	16	13	8	0	20	6	4	4
Indiana	45	23	0	10	19	13	0	10	14	10	10
Iowa	33	22	6	40	5	4	0	20	0	0	
Kansas	24	15	0	8	9	9	0	20	1	0	0
Kentucky	103	79	6	18	72	63	0	23	39	39	20
Louisiana	271	157	11	25	71	69	1	60	169	143	10
Maine	14	10	5	<2,000	9	4	0	1	2	1	2
Maryland	21	21	0	6	13	4	0	1	1	0	0
Massachusetts	25	15	0	6	9	9	1	550	7	7	300
Michigan	125	80	3	20	38	31	0	10	0	0	
Minnesota	41	29	0	8	29	26	0	20	20	20	10
Mississippi	20	12	1	11	66	41	0	25	51	50	10
Missouri	72	51	10	80	14	14	1	60	2	0	0
Montana	101	65	5	55	74	72	3	30	5	5	10
Nebraska	99	70	6	89	16	16	2	211	0	0	
Nevada	11	6	1	20	10	10	0	20	0	0	
New Hampshire	5	3	0	2	19	15	0	16	2	2	2
New Jersey	62	40	27	<2,400	38	31	0	12	10	2	1
New Mexico	53	58	19	714	26	26	3	40	1	1	1
New York	185	179	137	220	122	57	7	230	6	3	3
North Carolina	67	56	6	50	44	41	32	80	18	17	20
North Dakota	78	63	5	26	65	62	2	30	3	2	10
Ohio	44	34	10	100	33	15	1	76	1	1	1
Oklahoma	52	36	2	30	60	60	6	100	7	6	8
Oregon	24	20	0	5	13	13	0	10	4	4	3
Pennsylvania	218	175	20	100	198	184	14	420	35	27	10
Rhode Island	8	8	4	10	4	4	4	210	0	0	
South Carolina	11	11	0	7	11	10	0	16	5	4	10
South Dakota	47	37	3	14	15	15	2	30	0	0	
Tennessee	28	18	1	190	47	35	1	840	1	0	0
Texas	162	135	3	30	29	29	1	50	3	2	1
Utah	43	29	8	270	15	15	0	20	0	0	
Vermont	4	4	0	6	1	1	0	1	0	0	
Virginia	17	15	7	50	4	4	0	2	0	0	
Washington	21	15	1	10	17	17	2	40	0	0	
West Virginia	53	39	5	25	51	38	0	22	15	0	0
Wisconsin	38	15	0	10	14	10	0	3	13	10	10
Wyoming	64	28	3	38	59	55	1	30	0	0	
United States	3,755	2,423	430	1,400	2,283	1,869	168	960	591	485	300

[a] Source: Pickering, 1976.

[b] N = Number of stations for which data are available.
N >0 = Number of stations with detectable cadmium.
Max = Maximum value found.

TABLE 2.5. CADMIUM LEVELS IN GROUND WATERS OF THE UNITED STATES[a,b]

	Dissolved Cadmium (Filtered Sample)				Total Cadmium (Unfiltered Sample)			
State	N	N >0	N >10 ppb	Max, ppb	N	N >0	N >30 ppb	Max, ppb
Alabama	54	31	1	32	7	5	0	7
Alaska	69	12	0	4	14	14	1	60
Arizona	21	7	0	9	0			
Arkansas	25	3	0	10	0			
California	30	12	3	1,400	7	7	0	10
Colorado	354	141	6	690	20	20	6	<7,500
Connecticut	22	8	2	21	0			
Delaware	0				1	0	0	0
Florida	232	75	7	21	338	192	0	20
Georgia	19[illegible]	102	7	18	0			
Idaho	10	3	0	1	0			
Indiana	50	32	1	60	0			
Iowa	13	13	0	10	0			
Kentucky	14	10	1	<10	12	9	0	5
Louisiana	24	9	0	4	0			
Michigan	17	5	1	100	23	8	0	21
Minnesota	40	14	9	2	145	145	0	10
Mississippi	4	3	0	4	9	7	0	4
Missouri	0				17	17	0	10
Montana	41	8	0	5	0			
Nebraska	211	40	1	13	0			
Nevada	90	79	65	900	0			
New Hampshire	0				16	2	0	8
New Jersey	24	18	14	500	39	12	0	10
New Mexico	99	36	8	51	8	8	3	750
New York	258	28	0	8	188	26	0	8
North Carolina	2	0	0	0	6	6	6	170
North Dakota	77	29	0	3	11	10	0	20
Ohio	0				2	1	0	1
Oklahoma	9	1	0	1	0			
Oregon	4	1	0	1	11	10	0	10
Pennsylvania	146	86	16	120	3	0	0	0
Rhode Island	0				12	10	0	1
South Dakota	60	28	8	28	9	9	0	12
Tennessee	0				18	4	0	2
Texas	50	20	0	1	0			
Utah	43	13	0	10	0			
Virginia	6	2	0	5	0			
Washington	41	33	0	10	0			
West Virginia	19	12	0	1	19	2	0	1
Wisconsin	31	13	0	9	0			
Wyoming	52	13	0	9	54	54	2	60
United States	2,431	940	150	1,400	859	448	18	750

[a] Source: Pickering, 1976.

[b] N = Number of stations for which data are available.
N >0 = Number of stations with detectable cadmium.
Max = Maximum value found.

TABLE 2.6. SUMMARY OF CADMIUM CONCENTRATIONS IN U.S. WATERS

	Surface Waters		Groundwater	
	Dissolved	Total	Dissolved	Total
Number of states sampled	50	49	36	25
Number of sites sampled	3,755	2,283	2,431	859
Positive values				
Number	2,423	1,869	940	448
Percent	64.5	81.0	38.7	52.2
Values >10 ppb				
Number	430		150	
Percent	11.5		6.2	
Values >30 ppb				
Number		168		18
Percent		7.4		2.1
Maximum value, ppb	1,400	960	1,400	750

1973). In 6 to 12 percent of the samples dissolved cadmium exceeded the 10 ppb limit recommended for drinking water, and in 2 to 7 percent total cadmium exceeded the 30 ppb water quality criterion recommended for cadmium by the National Academy of Sciences. The USGS data indicate that on the average, groundwater quality with respect to cadmium exceeds that of surface waters.

Although the ocean is the final sink for most of the cadmium dispersed to the environment, the present concentration of cadmium in the oceans, approximately 0.11 ppb, is much lower than that which would be calculated from the cumulative natural input, suggesting that cadmium is being continuously deposited from ocean waters (Fleischer et al., 1974). James of Stanford University suggests that one vehicle for bioaccumulation of cadmium in polluted waters might exist because of the metal's strong propensity to form chloride ion complexes. These complexes would make cadmium more available to marine organisms, because it is less removable than, say, lead and zinc, through oxide and carbonate sedimentation (Anonymous, 1977). There is no national program for monitoring sediment concentrations of cadmium.

Local Monitoring of Cadmium Concentrations

Results of an unpublished EPA study (U.S. Environmental Protection Agency, 1976b) present information on the cadmium contents observed in

395 sediment samples collected from harbors along the shores of the Great Lakes between Erie, Pennsylvania, and Duluth, Minnesota. As shown in the frequency distribution curve in Figure 2.7, over 90 percent of the samples contained less than 10 ppm and over 80 percent contained less than 5 ppm. The median was below 2 ppm. Eight samples, all from Michigan City, Indiana, exceeded 35 ppm; these would appear to represent gross contamination from a point source.

The Ohio River Valley Water Sanitation Commission has monitored for cadmium on the Ohio River and its major tributaries. Some of the recent, 1975-1976, results are presented in Table 2.7 to illustrate typical surface water cadmium concentrations in an industrial area. It is apparent that there is no consistent trend of increasing cadmium concentration with downstream distance; if anything, the lower values are found closer to the junction of the Ohio River and the Mississippi River at Cairo, Illinois. Cadmium concentrations above 2 ppb are typically found in the upstream reaches, above Cincinnati, Ohio. These data suggest that dilution (or precipitation) is occurring as the river proceeds downstream.

The Coeur d'Alene region of Idaho is an important lead-zinc district in which mining and smelting operations have been conducted for many years. The South Fork of the Coeur d'Alene River passes the mining and smelting operations at Kellogg and Wallace on its way to Coeur d'Alene Lake, approximately 60 km to the west. Elevated cadmium concentrations have been measured in this river. Mink et al. (1971) reported cadmium concentrations as high as 450 ppb. Roberts et al. (1975) reported mean concentrations ranging between 150 and 300 ppb for 100 samples taken from the river in 1970 and 1971; the range of individual concentrations was from 1 to 3,600 ppb. These data are believed to be total cadmium, i.e., the samples were unfiltered. Maxfield et al. (1974), investigating the sediments in the lake, observed cadmium concentrations in the sediments ranging from 30 to 90 ppm. Concentrations were greatest in silt, typical of mine tailings.

Cadmium is found to concentrate in sediments, and whereas water concentrations are in the ppb range, cadmium concentrations in sediments are in the ppm range. A number of investigations of cadmium concentrations in sediments have been frequently conducted in connection with the study of a known or suspected point source. Perhac (1974) investigated heavy metal concentrations in the aquatic environment in a region of Tennessee which was highly mineralized, including sphalerite (ZnS). He found cadmium concentrations of 3 to 8 ppm in local stream sediments. In this same region of Tennessee, Perhac and Tamura (1977) found cadmium concentrations approaching 100 ppm in bottom sediments downstream from a zinc mill. Even so, the dissolved cadmium in the overlying river water was only 3 ppb, which is typical of the region.

Yost et al. (1975) found high cadmium contents in the sediments of Palestine Lake, a small lake in Indiana which had received effluents from a plating operation for a period of years. Contents ranged from 0.7 to 19.8 ppm, with a mean concentration of 9.1 ppm. Similarly, they found sediments

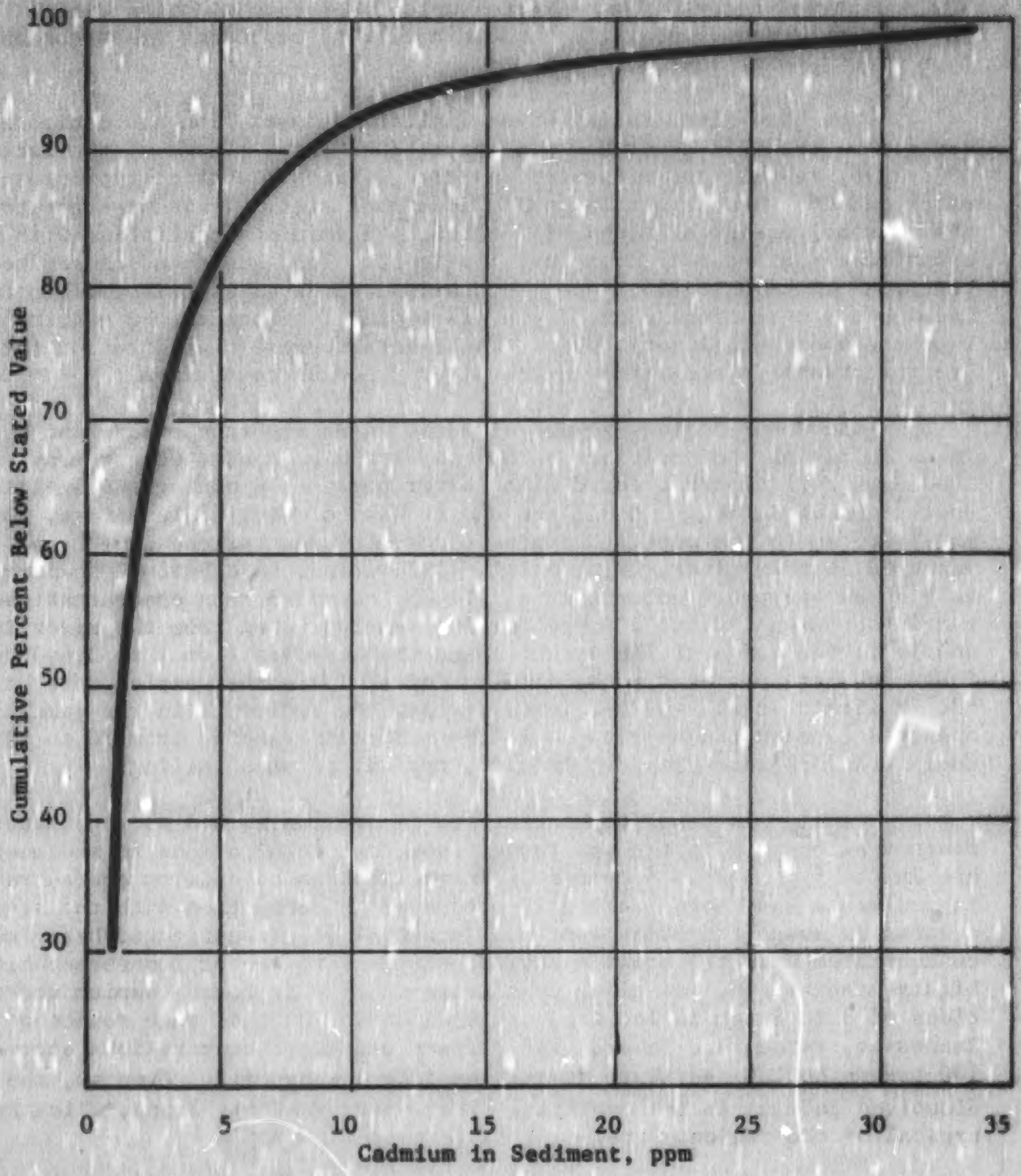


Figure 2.7. Frequency distribution of cadmium in Great Lakes sediments.

TABLE 2.7. CADMIUM CONCENTRATIONS IN THE OHIO RIVER AND SOME OF ITS TRIBUTARIES[a]

Location	Date of Data Collection	Number of Samples	Frequency of Detection, %	Concentration, ppb	
				Mean	Range
Illinois					
Ohio River at Joppa	9/75-4/76	7	57	0.86	0-2
Indiana					
Ohio River at Evansville	11/75-4/76	6	50	0.50	0-1
Ohio River at Uniontown	11/75-4/76	6	50	1.0	0-3
Kentucky					
Licking River, Kenton County	9/75-4/76	8	25	0.25	0-1
Ohio River at Louisville	10/75-4/76	7	43	0.57	0-2
Ohio River at West Point	11/75-4/76	6	83	1.5	0-2
Green River at Sebree	9/75-4/76	7	57	0.57	0-1
Ohio					
Ohio River at East Liverpool	9/75-3/76	8	100	2.13	1-4
Ohio River at Shadyside	9/75-10/75	2	50	2.5	0-5
Muskingum River at Marietta	9/75-4/76	8	100	2.13	1-4
Ohio River at Belleville	9/75-4/76	8	100	2.13	1-4
Ohio River at Kyger Creek	10/75-4/76	7	100	1.57	1-3
Ohio River at Kenova	11/75-4/76	6	83	1.33	0-4
Scioto River at Lucasville	10/75-4/76	7	71	0.96	0-2
Ohio River at Meldahl	10/75-4/76	7	86	1.14	0-2
Ohio River at Cincinnati	10/75-4/76	7	43	0.43	0-1
Little Miami River	9/75-4/76	8	50	0.63	0-2
Great Miami River	10/75-4/76	6	100	1.0	0-1
Pennsylvania					
Allegheny River at Oakmont	9/75-3/76	7	86	2.14	0-4
Monongahela River at South Pittsburgh	9/75-3/76	7	86	1.86	0-6
Ohio River at South Heights	9/75-3/76	8	88	2.25	0-6
Beaver River at Beaver Falls	9/75-3/76	8	63	1.13	0-3
West Virginia					
Ohio River at Pike Island	9/75-4/76	8	88	2.00	0-4
Ohio River at Willow Island	9/75-4/76	8	75	2.38	0-5

[a] Source: Ohio River Valley Water Sanitation Commission, 1975, 1976.

in the Grand Calumet River in the highly industrialized Chicago area to range from 1 to 20 ppm, with means in the 6 to 7 ppm range. Kneip et al. (1975) found, in Foundry Cove, near Cold Springs on the Hudson River in New York, extremely high cadmium contents in sediments immediately below the effluent outfall of a nickel-cadmium battery plant. In 1971, values ranging from 33 to 60,700 ppm were detected; in 1973, the range was from 3 to 48,000 ppm. These reports are illustrative of the cadmium concentrations which can be reached in sediments exposed to cadmium sources and are confirmed by other studies in similar environments. However, they represent localized problems and cannot be considered representative of average cadmium concentrations in sediments.

Sediments not exposed to industrial or mining wastes are lower in cadmium and may contain only fractions of a ppm. Illustrative are the results of Proctor et al. (1975) in the Meramec River Basin of Missouri. In nonmineralized areas, mean cadmium concentrations in river sediments were 0.3 to 0.4 ppm, whereas in the mineralized area near Viburnum, the range was from 0.2 to 18 ppm, with a mean of 4 ppm.

Cadmium concentrations in marine sediments have been investigated at a number of U.S. locations in harbors, estuaries, and offshore. Harbor sediments can carry appreciable contents of cadmium. Villa and Johnson (1974) determined concentrations of less than 1 to 654 ppm, with an average concentration of 6.3 to 6.6 ppm in Baltimore Harbor. Roberts et al. (1975) found 3.3 to 29 ppm, mean 12.5 ppm, in the inner portion of Boston Barbor, and 0.8 to 13 ppm, mean 6.2 ppm, in the outer harbor. Moyer and Budinger (1974) found values ranging from 0.7 to 1.5 ppm in San Francisco Harbor.

Cadmium concentrations in offshore sediments appear to be much lower than harbor concentrations, even in the vicinity of dumpsites, presumably as a result of large dilution provided by ocean dumping. Szucs and Oostdam (1975), investigating heavy metals in sediments of ocean dumpsites found, for example, that around the present and former dumpsite used by Philadelphia for sewage sludge, mean cadmium concentrations ranged from 0.05 to 0.13 ppm, with a maximum concentration of 0.37 ppm in a slough close to the former dumpsite.

Information describing the long-term fate of cadmium in nonmarine sediments appears to be lacking. The presumption is that the cadmium is fairly well immobilized, and barring physical disruption, such as by dredging, will remain so. River bottom sediments are likely to be gradually transported to the lake or marine estuary into which the river empties, but it does not necessarily follow that a significant fraction of the cadmium will be liberated in this transit.

DRINKING WATER

One of the first broad-based investigations of cadmium concentrations in drinking water was included as a part of the Community Water Supply

Survey conducted in 1969 by the U.S. Public Health Service (U.S. Department of Health, Education, and Welfare, 1970). The study was designed to give an assessment of drinking water quality in urban and suburban areas in each of the nine HEW regions. It included an entire Standard Metropolitan Statistical Area (SMSA) in eight regions; in Region I, the entire state of Vermont was studied. As reported by Taylor (1971), in only 4 out of 2,595 distribution samples (0.15 percent) did cadmium content exceed the 10 ppb Drinking Water Standard; these were found in 3 out of the 969 water systems investigated. The three systems each served a population of less than 100,000 people. The average concentration was 3 ppb; the maximum sample contained 3.94 ppm. Method of analysis was atomic absorption (McCabe et al., 1970). No data were presented by either Taylor or McCabe et al. on the number of samples below the limit of detection, estimated to be 1 ppb. In a later paper, McCabe (1974) described the average cadmium concentration determined by the study as 1.3 ppb and also claimed that 63 percent of the samples were above a 1 ppb detection limit.

At the time EPA was established (1970), it was assigned the responsibility of certifying water supply systems serving interstate carriers, formerly the responsibility of the Public Health Service, Department of Health, Education, and Welfare. Analytical data for 735 sampling points covering the U.S. and possessions through March 1, 1975, have been reported and summarized by EPA (U.S. Environmental Protection Agency, 1975a). Out of 594 analyses, none failed to meet the USPHS Drinking Water Standards of 1962 for cadmium (10 ppb), and for only seven samples (1.2 percent) were detectable limits higher than the standards.

In areas not known to be polluted from mining, smelting, or other industrial cadmium sources, the concentration of cadmium in water is generally less than 1 ppb in both natural and drinking waters (Friberg et al., 1971). These observed levels fall well below the World Health Organization's recommendation of less than 5 ppb cadmium (Joint FAO/WHO Expert Committee on Food Additives, 1972). Because dissolution of metals from pipes is most likely to occur in areas having soft "acid" (pH 5-6) water supplies, EPA has conducted special studies of water systems where the water is particularly corrosive to the distribution system and plumbing. Results of two of these studies indicate that in Boston none of the homes were found to exceed the 10 ppb USPHS standard while in Seattle, 7 percent of the homes exceed the standard (Deane et al., 1976). While low levels of cadmium are found in municipal water supplies, additional uptake may be occurring between the inlet and the consumer. A study reported by McCabe et al. (1970) showed that 15 percent of water samples had picked up cadmium between the treatment plant and the distribution system.

SLUDGE

The sludge resulting from treatment of wastewater contains small but useful concentrations of the fertilizer elements, nitrogen, phosphorus, and potassium as well as useful organic matter. It also contains most of the toxic elements, including heavy metals, present in the raw wastewater, since these tend to distribute to the sludge. Disposal options for sludge are fairly limited. Municipal sewage sludge disposition in 1975 in the U.S. has been reported to be 15 percent in the ocean, 25 percent in landfills, 35 percent by incineration, and 25 percent by application to land (CAST, 1976).

There is a wide range in reported values for metal contents in sludge. There appears to be a significant correlation between the degree of industrialization and elevated metal levels in sludges; and cadmium also follows this pattern. Electroplating has been a major source of cadmium in wastewater heretofore, and other industrial processes have contributed. Data on cadmium contents of sewage sludge from U.S. cities have been compiled from various sources by the EPA Office of Solid Waste and are given in Table 2.8.

The extreme variability between cities is quite evident. The lowest values are for cities with little or no industry, and cadmium contents as low as 2 ppm are reported. At the other extreme are Frankfort, Indiana, with 3,171 ppm and Owosso, Michigan, with 1,100 ppm. Both are relatively small (15,000 to 20,000 people) but fairly industrialized. Each has a large battery manufacturer, and Owosso also has electroplaters.

Sommers et al. (1976) also obtained data on the variability over a 22-month period of the cadmium content of sludge from individual sewage plants. As illustrated in Table 2.9, although the between-samples variations were large, the between-plant variations were significantly larger. The number of samples from each plant ranged from 5 to 7. Salotto et al. (1974) reported the same conclusion from their study of about 100 samples collected from 33 wastewater treatment plants in 13 states from the summer of 1971 through 1973.

Also reported in Table 2.8 are the cadmium:zinc ratios for the cities where the cadmium content was greater than 25 ppm. Cadmium concentrations ranged from 0.2 to 70 percent of the zinc concentrations. In 5 cities out of the 60 reported the ratio was below the 1 percent advocated by the EPA Draft Document on Acceptable Methods for the Utilization or Disposal of Sludges (U.S. Environmental Protection Agency, 1974).

Even before the promulgation of EPA effluent guidelines regulations, some cities had enacted ordinances to limit the discharge of heavy metals to the sewer system. The Metropolitan Sanitary District of greater Chicago has had such an ordinance since 1969 for the purpose of protecting the biological processes utilized in sewage treatment (Zenz et al., 1975). The Chicago ordinance, which limits cadmium concentration in incoming sewage to 2 ppm, has produced a significant downward trend in cadmium concentrations, as

TABLE 2.8. SEWAGE SLUDGE DATA ON U.S. CITIES (COMPILED OCTOBER 1976)[a]

City	Year	Cadmium Content, ppm	Cd/Zn Ratio, %[b]	Present Disposition	Source of Information[c]
New York NY					
(Metropolitan Area)				Ocean	
Hampstead-Bay Park	1975	70	6.3		Interstate Sanit. Com., 1975
Long Beach	1975	18			"
Bowery Bay	1975	47	0.9		"
Coney Island	1975	8			"
Hunts Point	1975	18			"
Jamaica	1975	4			"
Newton Creek	1975	71	1.9		"
Owls Head	1975	18			"
Port Richmond	1975	3			"
Rockaway	1975	16			"
Tallmans Island	1975	6			"
26th Ward	1975	17			"
Wards Island	1975	6			"
Hempstead-West Long Beach	1975	4			"
Yonkers	1975	163	8.2		"
Chicago IL	1976	35	3.0	Land application	Ehorn (n.d.)
North Side	1976	180	8.1	Give away	"
Calumet	1976	42	1.8		"
Hanover Park	1976	10			"
Lemont	1976	16			"
W. Southwest	1976	210	7.8		"
Los Angeles CA	1972-73	171	3.7	Ocean, compost	Furr et al., 1976
Philadelphia PA					
N.E. Plant	1976	90	2.0		Ehorn (n.d.)
S.W. & S.E.	1976	25	1.0		"
Detroit MI		290	2.5	Incineration	"

TABLE 2.8. (Continued)

City	Year	Cadmium Content, ppm	Cd/Zn Ratio, %^{b}	Present Disposition	Source of Information^c
Houston TX	1972-73	112	4.4	Fertilizer-soil conditioner	Furr et al., 1976
North Side	1976	17	0.2		Public Works Director
Simms	1976	22			"
Baltimore MD		25	0.5	Landfill	Ehorn (n.d.)
Back River		7			"
Patapsco		9			"
Dallas TX	1976	59	5.7	Lagoon	Public Works Director
Washington DC	1975	22		Land application, landfill	Camp et al., 1975
Cleveland OH				Landfill	
Southerly		390	10.0		Ehorn (n.d.)
Westerly		578	8.0		"
Indianapolis IN				Incineration, land application	"
Belmont		240	17.0		
Southport		260	17.0		"
Milwaukee WI	1972-73	444	32.0	Miloganite-soil conditioner	Furr et al., 1976
Jones Island		107	9.0		Ehorn (n.d.)
South Shore		50	1.5		"
San Francisco area	1975	15		Landfill, land application	Brown and Campbell, 1975
Boston MA	1973-75	82		Ocean	EPA (n.d.)
Denver CO	1972-73	46	1.6	Land application	Furr et al., 1976
Seattle WA	1972-73	64	3.5	Landfill or soil conditioner	"
Atlanta GA	1972-73	104	3.7	Landfill or soil conditioner	"
Newark NJ	1975	173	4.1	Incineration	Interstate Sanit. Com., 1975
Miami FL	1972-73	149	10.0	Soil conditioner	Furr et al., 1976
Tampa FL	1975	10		Land application	Greenley and Hansen, 1975
Little Ferry NJ	1975	240		N.A.	Interstate Sanit. Comm. (1975)
Grand Rapids MI	Prior to 1974	480	5.1	N.A.	Blakeslee, 1973

TABLE 2.8.(Continued)

City	Year	Cadmium Content, ppm	Cd/Zn Ratio, $\%^{b}$	Present Disposition	Source of Information^{c}
Flint MI	Prior to 1974	20		N.A.	Blakeslee, 1973
Syracuse NY	1972-73	200	11.0	Solvay process	Furr et al., 1976
Madison WI		73	3.1	N.A.	Ehorn (n.d.)
Warren MI	Prior to 1974	110	3.1	N.A.	Blakeslee, 1973
Macon GA	1976	6		Land application	SCS Engineers, 1976
Elizabeth NJ	1975	72	6.0	N.A.	Interstate Sanit. Com., 1975
Camden NJ		601	56.0	N.A.	Ehorn (n.d.)
Springfield MO	1976	54	1.2	Land application	SCS Engineers, 1976
Saginaw MI	Prior to 1974	48	6.5	N.A.	Blakeslee, 1973
Pontiac MI	"	12		N.A.	"
Kalamazoo MI	"	12		N.A.	"
Ann Arbor MI	"	4		N.A.	"
Anderson IN	1972-74	170	5.0	Land application	Sommers et al., 1976
Kokomo IN	1972-74	806	5.0	Land application	"
Wyoming MI		14		N.A.	Blakeslee, 1973
Bay City MI	Prior to 1974	80	6.0	N.A.	"
Jackson MI	"	520	8.0	N.A.	"
Danville VA	1976	18		Land application	SCS Engineers, 1976
Muskegon MI	Prior to 1974	166	5.0	N.A.	Blakeslee, 1973
Linden NJ	1975	65	1.5	N.A.	Interstate Sanit. Com., 1975
Battle Creek MI	Prior to 1974	8		N.A.	Blakeslee, 1973
Port Huron MI	"	8		N.A.	"
East Lansing MI	"	6		N.A.	"
Ithaca NY	1972-73	66	4.0	Soil conditioner	Furr et al., 1976
Easton PA		16		Land application	
Midland MI	Prior to 1974	10		N.A.	Blakeslee, 1973
Columbus IN	1976	2		Land application	SCS Engineers, 1976
Holland MI	Prior to 1974	10		N.A.	Blakeslee, 1973
Ypsilanti MI	"	166	2.0	N.A.	"
Sayreville NJ	1975	39	1.1	N.A.	Camp et al., 1975
Hopkinville IN	1976	18		Land application	SCS Engineers, 1976

TABLE 2.8. (Continued)

City	Year	Cadmium Content, ppm	Cd/Zn Ratio, %[b]	Present Disposition	Source of Information[c]
Xenia OH	1976	80	0.6	Land application	SCS Engineers, 1976
Monroe MI	Prior to 1974	8		N.A.	Blakeslee, 1973
Marquette MI	"	2		N.A.	"
Muskegon Heights MI	"	150	1.0	N.A.	"
Mt. Clemons MI	"	12		N.A.	"
Trenton MI	"	8		N.A.	"
Sault Ste. Marie MI	"	2		N.A.	"
Logansport IN	1972-74	663	4.0	Land application	Sommers et al., 1976
Traverse City MI	Prior to 1974	10		N.A.	Blakeslee, 1973
Adrian MI	"	260	5.0	N.A.	"
Owosso MI	"	1,100	20.0	N.A.	"
Mt. Pleasant MI	"	14		N.A.	"
Benton Harbor MI	"	220	1.7	N.A.	"
Escanaba MI	"	10		N.A.	"
Dixon IL	1976	16		Land application	SCS Engineers, 1976
Frankfort IN	1976	3,171	70.0	Land application	"
Las Virgenes CA	1976	5		Land application	"
Peru IN	1972-74	154	6.0	Land application	Sommers et al., 1976
Crawfordsville IN	1972-74	15		Land application	"
Iron Mountain MI	Prior to 1974	6		N.A.	Blakeslee, 1973
Albion MI	"	48	1.5	N.A.	"
Niles MI	"	14		N.A.	"
Grand Haven MI	"	14		N.A.	"
Menominee MI	"	4		N.A.	"
Cadillac MI	"	36	3.0	N.A.	"
Lebanon IN	1972-74	40	1.6	Land application	Sommers et al., 1976
Noblesville IN	1972-74	12		Land application	"
Marshall MO	1976	16		Land application	SCS Engineers, 1976
Wilmington OH	1976	15		Land application	"
Charlotte MI	Prior to 1974	14		N.A.	Blakeslee, 1973
Ironwood MI	"	4		N.A.	"

TABLE 2.8. (Continued)

City	Year	Cadmium Content, ppm	Cd/Zn Ratio, %[b]	Present Disposition	Source of Information[c]
Hancock MI	Prior to 1974	4		N.A.	Blakeslee, 1973
Three Rivers MI	"	44	1.0	N.A.	"
Chippewa Falls WI	1976	7		Land application	SCS Engineers, 1976
Litchfield IL	1976	6		Land application	"
Kendallville IN	1976	28	0.6	Land application	"
Marshall MI	1976	16		N.A.	"
Gladstone MI	Prior to 1974	4		N.A.	Blakeslee, 1973
Howell MI	"	18		N.A.	"
Manistique MI	"	4		N.A.	"
Tipton IN	1972-74	11		Land application	Sommers et al., 1976
Milford MI	Prior to 1974	2		N.A.	Blakeslee, 1973
Essexville MI	"	4		N.A.	"
Norway MI	"	2		N.A.	"
St. Ignace MI	"	4		N.A.	"
Constantine MI	"	16		N.A.	"
Dexter MI	"	36	2.5	N.A.	"
Lanse MI	"	8		N.A.	"

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[a] Source: U.S. Environmental Protection Agency, Office of Solid Waste Management, 1976. Includes the references listed in Footnote (c).

[b] The Cd/Zn ratio is only listed when the Cd content is greater than 25 ppm.

[c] Sources of Information:

Blakeslee, Paul A. 1973. "Monitoring Considerations for Municipal Wastewater Effluent and Sludge Application to the Land", Recycling Municipal Sludges and Effluents Joint Conference, Champaigne IL.

Brown and Caldwell. 1975. San Francisco Bay Area Municipal Wastewater Solids Management Study (May 1975).

Camp, Dresser, and McKee. 1975. Alternative Sludge Disposal Systems for the District of Columbia Water Pollution Control Plant at Blue Plains (December 1975).

TABLE 2.8. (Continued)

[c]Sources of Information (Continued)

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TABLE 2.9. VARIABILITY OF CADMIUM CONTENTS IN SEWAGE SLUDGES[a]

	Cadmium Content, ppm				V.,[b]
	Minimum	Maximum	Median	Mean	%
Anderson	109	372	170	210	45
Crawfordsville	4	39	15	19	67
Kokomo	483	1,177	806	846	27
Lebanon	3	150	40	53	95
Logansport	24	756	663	503	63
Noblesville	12	163	12	42	160
Peru	22	256	154	136	69
Tipton	11	32	11	16	54
				Average	72

[a] Source: Sommers et al., 1976.

[b] V. = Standard deviation expressed as a percentage of the mean.

evidenced by typical sludge concentrations from the Calumet Sewage Treatment Plant:

Year	Sludge Source	Cadmium Concentration, ppm
1969	Lagoons	190
1972	Anaerobic digester	100
1974	Anaerobic digester	54

Cadmium concentrations reported in digested sludges from this plant in Chicago have been reduced by 72 percent during the period 1969-1974. Data for 1976 were similar to those for 1974, indicating that industrial pretreatment has reached its level of effectiveness (CAST, 1976).

Simultaneously, zinc concentrations have also dropped markedly, from 5,500 to 2,800 ppm, and the cadmium:zinc ratio has steadily decreased from 3.4 to 1.9 percent. It is still a long way from the 1 percent ratio proposed in the EPA draft guidelines.

There has been some controversy over the need for a cadmium:zinc ratio of 1 percent or less, especially in view of the fact that most sludges, from all but essentially unindustrialized areas, will not achieve this ratio

(Zenz et al., 1975). They note that the EPA discussion of the draft guidelines stated that more than 50 percent of the 188 sludges examined would not qualify.

In view of the variability of sludges, as indicated above, only very approximate estimates of input to the environment from this source can be made. Fulkerson and Goeller's (1973) estimate assumed a cadmium content in sludge of 15.6 ppm, based on some Swedish data. On the basis of recent U.S. data such as described above, 15.6 ppm appears to be low for the more industrialized wastes of this country. Sargent and Metz (1975), using an assumed average cadmium content of 75 ppm, derived an estimate of 300/MT yr from sludge. They further assumed that 60 percent is applied to land, 10 percent is dumped at sea, and 30 percent is incinerated, producing 20 metric tons of air emissions, at an incinerator scrubber efficiency of 80 percent.

ROCKS AND SOILS

Cadmium is one of the minor nonferrous metals, ranking 57th in abundance in the earth's crust, between mercury and silver, 0.1 to 0.5 ppm (Howe, 1964). Illustrative of the cadmium concentration in rocks and geologic formations are the data summarized by Fleischer et al. (1974), shown in Table 2.10. Igneous rocks appear to fall in the lower end of the cadmium concentration range, with the average concentration being 0.25 ppm or below. Of the sedimentary rocks, limestone is also low in cadmium, shales are higher on the average; and the cadmium content appears to increase with increasing carbonaceous content.

Since rocks are the precursors of soils, cadmium concentrations in soils undisturbed by man would be expected to approximate those found in rocks. This appears to be the case. Fleischer et al. (1974) noted that recent analyses of uncontaminated soils indicate that normal contents of cadmium are less than 1 ppm, perhaps about 0.4 ppm on the average. Connor and Shacklette (1975) have analyzed a large number of soil samples from rural Missouri farmland (Table 2.11), finding a mean cadmium concentration of less than 1 ppm.

Additional data on cadmium concentrations in U.S. soils are supplied by the results of EPA's 1972 National Soils Monitoring Program, which, in addition to the regular pesticide analyses, also analyzed soil samples for four heavy metals: lead, mercury, cadmium, and arsenic. Five Standard Metropolitan Statistical Areas (SMSA) were selected at random, and one 2.56 km^2 site within city limits (urban) and one 51.8 km^2 site outside city limits (suburban) were randomly selected for each SMSA. Each site was classified as "lawn", mowed or cultivated, or "waste", uncared for. Results of cadmium analyses are shown in Table 2.12 (Gowen et al., 1976). The comparison of lawn and waste sites indicated no statistically significant differences, supportive of the hypothesis that the deposition is from airborne fallout, which would fall equally on both types of sites within a given urban or suburban area. These data were not normally distributed as shown by tests for skewness and kurtosis, but tended to fit a lognormal distribution, and the geometric mean is consequently regarded as providing a more meaningful estimate of central tendency.

TABLE 2.10. CADMIUM CONTENT OF ROCK TYPES[a]

Rock Type	Concentration, ppm Mean	Concentration, ppm Range
Igneous Rocks		
Alkalic rocks	0.25	0.004-0.90
Basalts, diabases, gabbros	0.13	0.01-1.00
Dunite		0.005-0.154
Eclogites	0.1	0.03-1.6
Granitic	0.2	0.01-1.6
Intermediate		0.02-0.32
Peridotite	0.3	<0.001-0.029
Rhyolite	0.23	0.03-0.57
Sedimentary Rocks		
Limestone	0.10	
Sandstone	<0.03	
Shales	1.4	<0.3-4.0
Organic content <0.5%	0.35	<0.3-0.8
Organic content 0.5%-1.0%	0.8	<0.3-1.8
Organic content >1.0%	2.0	0.5-8.4

[a] Source: Fleischer et al., 1974.

TABLE 2.11. CADMIUM CONCENTRATIONS IN MISSOURI SOILS (in ppm)

Soil Horizon	Number of Samples	Concentration, ppm Mean	Concentration, ppm Range
Plow zone, corn field			
Oak-hickory forest	10	<1	<1-1.5
Plow zone, soybean field			
Glaciated prairie	10	<1	<1-1.0
Unglaciated prairie	10	<1	<1-2.5
Plow zone, pasture field;			
Floodplain forest	10	<1	<1-1.0
Oak-hickory forest	10	<1	<1-2.5
Glaciated prairie	10	<1	<1-4.5
Surface horizon	1,140	<1	<1-11

[a] Source: Connor and Shacklette, 1975.

TABLE 2.12. CONCENTRATIONS OF CADMIUM IN URBAN AND SUBURBAN SOILS--1972[a]

SMSA	Number of Samples		Cadmium, ppm[b] Arithmetic Mean	Cadmium, ppm[b] Geometric Mean	Cadmium, ppm[b] Extremes	Percent of Positive Detections
Des Moines IA	59	Urban	0.89	0.640	0.1-3.56	100
	25	Suburban	0.28	0.124	0.00-1.76	80
Fitchburg MA	26	Urban	0.13	0.059	0.00-0.70	62
	10	Suburban	0.13	0.051	0.00-0.38	60
Lake Charles LA	16	Urban	0.36	0.015	0.00-5.32	25
	54	Suburban	0.01	0.002	0.00-0.11	7
Pittsburgh PA	51	Urban	1.21	0.743	0.00-4.95	98
	138	Suburban	0.90	0.454	0.00-8.03	93
Reading PA	10	Urban	0.63	0.261	0.00-1.70	90
	41	Suburban	0.25	0.039	0.00-2.45	44

---

[a] Source: Gowen et al., 1976.

[b] Sensitivity 0.5 ppm.

In an investigation of the distribution of metals in the soils of a mining district, in this case the Coeur d'Alene lead-zinc district in Idaho, Cannon (1969) reported that the pattern of zinc-soil concentrations over 600 ppm correlated well with the occurrence of ore. Cadmium-high (greater than 5 ppm) areas in the eastern part of the district were found to be related to mineralized ground, but the values near Kellogg were thought to be affected by smelter contamination.

The possibility that cadmium mobility in soil is pH dependent has been suggested by Munshower (1972) in his discussion of an investigation of the region around the East Helena, Montana, smelter (Table 2.13). In his opinion, the pH variations between sites may account for some of the differences; and he noted that the correlation between cadmium mobility in the soil and pH was strong. Whenever any horizon reached or exceeded a pH of 7, the cadmium concentrations in lower horizons dropped to normal or near normal levels. The soil reservoir of introduced cadmium is restricted essentially to the top 2 to 5 cm (1 to 2 in.), is geographically distributed in relation to distance from the smelter and the prevailing winds, and is normally not transferred to lower horizons. Therefore, the only exit from the system by cadmium is by erosion or cropping, and not by leaching. Interpretation of long-term changes indicate a half-life for this introduced cadmium in the grassland habitat in excess of 1,000 years; it would be shorter in cultivated lands.

Fleischer et al. (1974) have summarized the results of a number of investigations of cadmium soil concentrations around smelters, including the extensive study of the East Helena smelter from which came the estimate of a total deposition of up to 236 metric tons (260 short tons) of cadmium within a radius of 16 km of the smelter stack. Other studies have been conducted around smelters, with similar findings of increased soil concentrations, including those of Cannon and Anderson (1971), Roberts et al. (1975), and Ratsch (1974).

Higher than normal (>0.4 ppm) cadmium soil concentrations can result from sources other than smelters--i.e., from use rather than production. Yost et al. (1975) in their study of northwestern Indiana, in the Gary and East Chicago area, have shown that cadmium soil concentrations are higher close to concentrated industrial areas than in rural areas removed from such sources (Table 2.14). Additionally, even in areas of normal soil concentrations, they confirmed the observations of Bolter et al. (1975) that concentrations in litter were significantly higher than in the underlying soil.

Fertilizers are a source of cadmium additions to soil. The small concentrations of cadmium associated with phosphate ores carry through the processing to fertilizer. There is a good deal of variability in cadmium content. Florida and South Carolina rock phosphate typically contains 8 to 16 ppm cadmium (Yost et al., 1975). Western rock phosphate, which will be drawn upon more in future as the eastern deposits are depleted, may contain several times as much cadmium, up to 50 ppm.

TABLE 2.13. CADMIUM CONCENTRATIONS IN SOIL NEAR EAST HELENA, MONTANA[a]

Soil Horizon, cm	Concentration, ppm	pH	Soil Horizon, cm	Concentration, ppm	pH
2.4 km[b]			11.3 km		
0.0-5.0	27.3	6.0	0.0-4.0	2.5	5.4
5.0-17.0	11.3	7.0+	4.0-7.5	0.7	7.6
17.0-30.0	0.6	7.0+	7.5-18.0	0.4	7.6
30.0-60.0	0.3		18.0-33.0	ND[c]	
4.0 km			16.9 km		
0.0-5.0	8.1	6.0	0.0-3.0	3.4	7.6
5.0-11.0	7.1	7.0	3.0-9.5	0.9	7.8
11.0-19.0	7.0	7.5	9.5-18.4	0.8	7.8
19.0-25.0	0.6	7.0+	>18.4	ND	
>25.0	0.3				
5.3 km			23.3 km		
0.0-3.5	4.7	6.5	0.0-6.5	1.8	6.6
3.5-7.0	7.2	6.5	6.5-10.0	0.8	6.8
7.0-15.0	0.2	7.4	10.0-18.0	0.3	7.2
15.0-35.0	0.2		18.0-21.0	0.3	
8.1 km			33.8 km		
0.0-7.5	4.2	5.2	0.0-2.5	1.5	6.4
7.5-26.0	1.4	5.4	2.5-5.0	0.4	6.7
26.0-37.0	0.2	8.2	5.0-8.0	0.1	6.9
37.0-42.0	0.2	8.2	8.0-23.0	0.2	7.4
			23.0-30.0	ND	

[a] Source: Munshower, 1972.

[b] Distance from smelter.

[c] ND = Not detected.

TABLE 2.14. CADMIUM SOIL CONCENTRATIONS IN NORTHWESTERN INDIANA[a]

Soil Horizon, cm	Concentration, ppm	Remarks
	East Chicago, Indiana[b]	
0-2.55	2.5-14.0	
9.4	2.51	Dunes
10.9	5.40	Marsh
12.2	5.95	Floodplain
	Willow Slough Fish and Game Area[c]	
Litter	1.03	Grassland
0-2.5	0.30	
2.5-10.2	0.20	
>10.2	0.14	
Litter	1.21	Black oak forest
0-2.5	0.23	
2.5-10.2	0.08	
>10.2	0.08	
Litter	1.16	Marsh
0-15.2	0.36	
	Jasper--Pulaski Fish and Game Area	
Litter	1.1	
0-15.2	0.4	

---

[a] Source: Yost et al., 1975.

[b] Less than 8 km from concentrated heavy industrial area.

[c] Approximately 80 km south of East Chicago.

The Yost team (1975) performed a study to determine the extent of cadmium buildup in soils associated with long-term application of known quantities of phosphate fertilizers, using "fertility plots" at the Purdue University Agronomy Farm. Soils from plots which, over a 20-year period, had received a variety of levels of fertilizer application were analyzed for cadmium. Soybeans and corn raised on these plots were also analyzed to determine whether or not there was a significant correlation between cadmium levels in soils and crops. No significant correlation was detected.

Definitive analytical data are relatively sparse on the effects of fertilizer application on soil cadmium contents; some data have been reported on Virgin Islands soil, as measured at the surface:

Cadmium, ppm	Treatment
0.15	Unfertilized soil
0.8	Fertilized
3.38	Phosphate fertilized

Overall, it appears that the cadmium concentrations in U.S. soils not excessively disturbed by man approximate those found in rocks, i.e., 0.2 to 0.5 ppm. The application of fertilizers does not appear to have generally raised this level above 1 ppm. Highest soil concentrations are found in the vicinity of smelters. These are proportional to the distance from the smelter. Several ppm of cadmium may be found in surface soils in the vicinity of major urban industrial areas.

Since the land and ocean sediments are the ultimate sinks for most of the cadmium annually dispersed to the environment, it appears inevitable that their concentrations will slowly increase. Except for the pockets of high concentration represented by landfills, the increase in average soil cadmium concentrations should proceed at an almost unmeasurable rate, especially as atmospheric emissions from past major point sources such as smelters are brought under control. Most of the increase may come from inadvertent sources such as fertilizers and the combustion of coals.

TERRESTRIAL BIOTA

Vegetation

Cadmium has been reported in plants over a large area of the United States. There is not, however, a national monitoring program or agriculture reporting program. Sargent and Metz (1975) reported that cadmium concentration in plants has an approximately 1:1 relationship with that of the soil. However, existing data show that cadmium is concentrated in plant tissues to varying degrees depending upon the species and the amount of cadmium in the environment. In laboratory studies by Page et al. (1972), the amount of cadmium in plant leaves varied between 9 ppm (beans) and 90 ppm (corn) when the concentration of culture solution was 0.1 μg Cd/ml (0.1 ppm) and from

35 ppm (beans) to 469 ppm (turnip) at a solution concentration of 1.0 μg/ml (1.0 ppm).

Yost and his associates (1975) found varying cadmium concentrations in herbaceous plants from industrial regions of northwestern Indiana with a range between 0.24 and 7.70 (Table 2.15). Similarly, they found tree stems to exhibit cadmium concentrations between 0.11 and 0.48 ppm. Hammons and Huff (1975) report mean cadmium concentrations in Alaskan grasses of 0.10 ppm. Shacklette (1972) reports plant concentrations in the Colorado Rockies which range from 0.03 to 1.50 ppm in stems and 0.07 to 0.97 ppm in leaves (Table 2.16).

The magnitude of species difference in ability to absorb cadmium appears to increase with increasing cadmium content in the environment. John (1973) has demonstrated a dramatic increase in cadmium content, particularly in the root portions of some plants grown on cadmium-contaminated soils (Figure 2.8). He reported cadmium concentrations of 1.8 to 12.2 ppm in various parts of 8 crops in control experiments as opposed to a range of 19.7 to 6,121.5 ppm when soil cadmium concentrations were increased to 200 mg cadmium per 1,000 g soil, air-dry basis. Hemphill et al. (1973) have shown that the main concentrations of cadmium in the roots of lettuce and radishes from less contaminated areas in Missouri were in the same range (0.7 to 1.6 ppm), while in samples from a small town where a smelter was located the cadmium concentration in lettuce (28.1 ppm) was about six times higher than that of radishes (4.7 ppm).

The work of numerous researchers has shown that different plant species, varieties, and plant tissues, when exposed to similar levels of cadmium, will contain different concentrations. For example, cadmium concentrations in corn grain are usually only 3 to 15 percent of those found in the leaf. In comparison, grain of soybeans, wheat, oats, and sorghum may contain 30 to 100 percent of the foliar levels. Additional studies have shown that leafy vegetables, such as lettuce, chard, spinach, and turnip greens, can accumulate levels undesirable to man (in excess of 100 ppm) without showing toxicity symptoms (CAST, 1976).

Many studies have been conducted to determine the cadmium content in plants as a function of distance from metal sources. For Kay County in Oklahoma, the cadmium contents of tree leaves were 32.9 and 5.8 ppm for samples collected at 1.6 and 7.2 km, respectively, from the cadmium source (Benenati, 1974). In Galena, Kansas, Lagerwerff et al. (1973) found that the cadmium concentrations in native grasses diminished from 8.6 to 1.4 ppm (dry weight) as the distance from the cadmium source increased from 0.3 to 2.4 km, and from 5.7 to 9.6 ppm with increasing distance from 1.7 to 0.3 km, even though cadmium was no longer being released at the time of sampling. In Tacoma, Washington, however, Ratsch (1974) found that cadmium levels in plants increased with increasing distance from cadmium sources, in this case smelters, up to 4.8 km (3 mi) and then decreased afterward. The mean cadmium concentrations of herbaceous grasses were 3.4 ppm at 0 to 1.6 km (0 to 1 mi), 6.6 ppm at 3.2 to 4.8 km (2 to 3 mi), and 2.4 ppm at 8 to 9.6 km (5 to 6 mi).

TABLE 2.15. CADMIUM CONCENTRATIONS IN PLANTS OF AN INDUSTRIAL REGION[a,b]

Species	No. of Samples	Cadmium Concentration, ppm dry weight
Whole Plant[c]		
Herbaceous		
Andropogon sp.	13	0.55
Anemone cylindrica	1	1.20
Apios americana	1	4.40
Aster sp.	4	2.42
Carex stricta	14	0.47
Coreopsis lanceolata	1	4.40
C. tripteris	8	4.85
Equisetum arvense	3	2.00
E. hyemale	17	0.87
Eryngium yuccifolium	6	0.37
Euphorbia corollata	5	0.86
Fragaria virginiana	7	0.89
Galium obtusum	1	1.80
Helianthus divaricatus	10	1.72
H. occidentalis	9	5.16
Hypoxis hirsuta	1	7.70
Juncus sp.	20	0.39
Hoeleria cristata	7	1.01
Liatris spicata	11	4.79
Liparis lilifolia	1	1.90
Lithosperum canescens	17	0.94
Lupinus perennis	1	0.70
Monarda fistulosa	3	0.93
Pedicularis canadensis	1	2.50
Phlox pilosa	2	0.75
Stem		
Woody		
Sweetgum, *Liquidambar styraciflua*		0.41
White oak, *Quercus alba*		0.16
Willow oak, *Q. phellos*		0.28
Winged sumac, *Rhus copallina*		0.11

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[a] Yost et al., 1975. Data collected June, 1974.

[b] Sampling location south of East Chicago--no lead smelters in the area.

[c] Whole above-ground plant unless specified.

TABLE 2.16. CADMIUM CONCENTRATIONS IN PLANTS REMOTE FROM INDUSTRIALIZATION

Organism		Organ	Mean Concentration, ppm dry weight
Alaskan grasses		Entire Plant	0.10[a]
Colorado blue spruce	*Picea pungens*	Stem	0.03[b,c]
Douglas fir	*Pseudotsuga menziesii*	Stem	0.20
		Leaves	0.07
Englemann's spruce	*Picea englemannii*	Stem	0.22
		Leaves	0.05
Juniper	*Juniperus communis nana*	Stem	0.26
		Leaves	0.11
Kinnikinnik	*Arctostaphylos uvo-ursi*	Stem	0.23
		Leaves	0.21
Limber pine	*Pinus flexilis*	Stem	0.14
		Leaves	0.10
Lodgepole pine	*Pinus contorta latifolia*	Stem	0.38
		Leaves	0.21
Mountain maple	*Acer glabrum*	Stem	0.17
		Leaves	0.09
Ponderosa pine	*Pinus ponderosa scopulorum*	Stems	0.22
		Leaves	0.11
Snowberry	*Symphoricarpus occidentalis*	Stems	0.09
		Leaves	0.12
Sticky laurel	*Ceanothus velutinus*	Stem	0.03
Quaking aspen	*Populus tremuloides*	Stems	0.77
		Leaves	0.45
Wild gooseberry	*Ribes* sp.	Stems	0.08
		Leaves	0.07
Willow	*Salix* sp.	Stems	1.50
		Leaves	0.97

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[a] Hammons and Huff, 1975. Alaska.

[b] Shacklette, 1972. Colorado, Rocky Mountains.

[c] Cadmium concentrations in stems range from 0.03 to 1.50 ppm while in leaves the range is 0.07 to 0.97 ppm.

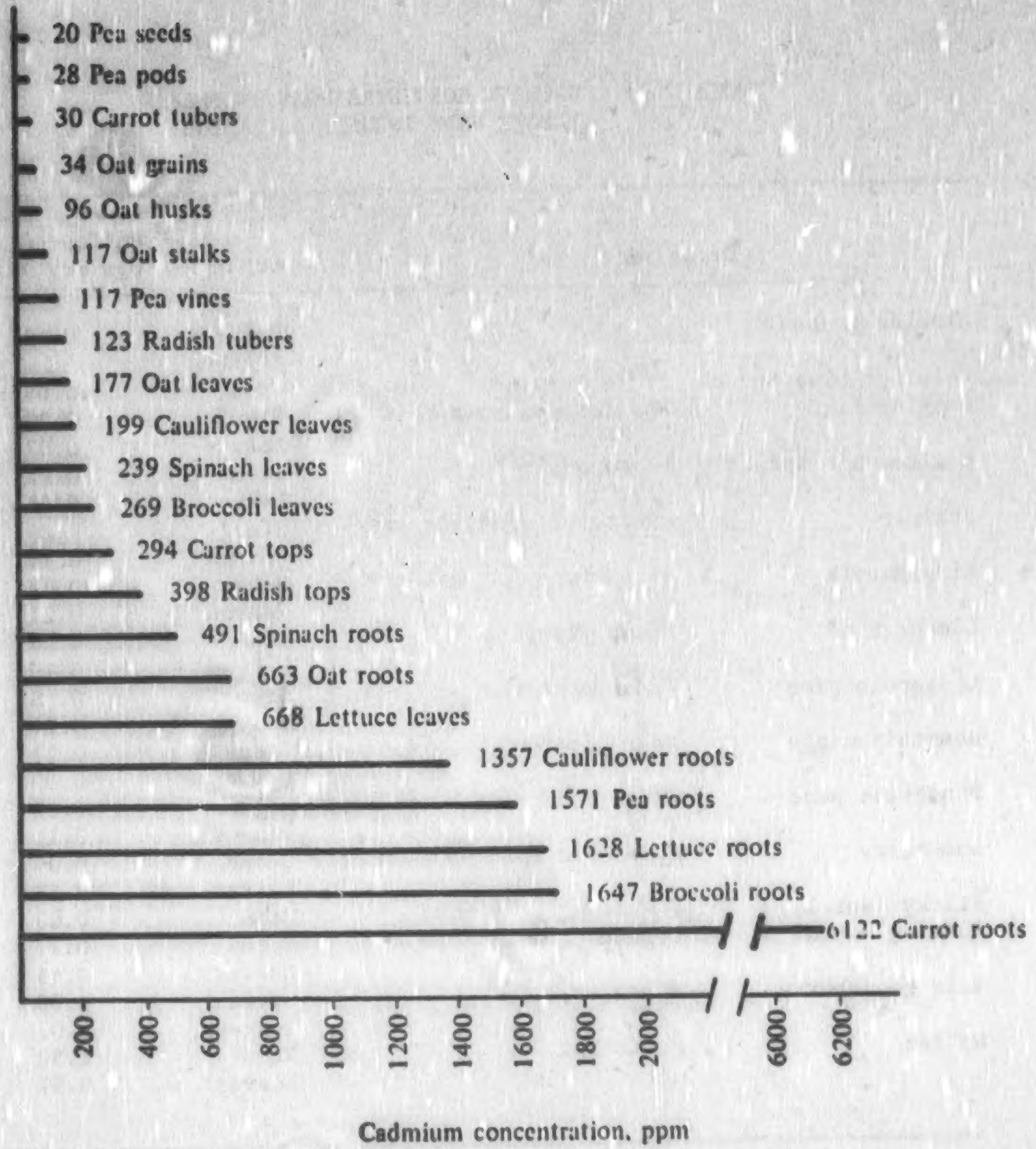

Figure 2.8. Cadmium in plants grown in 200 mg Cd/1000 g soil (John, 1973).

Hemphill et al. (1973) have shown that plants along traffic routes were higher in cadmium concentration but diminished with increasing distance from the road. Connor et al. (1971) found that the cadmium concentration in cedar trees along the lead-ore truck route near Centerville, Missouri, was more than three times the amount found in cedars from off-road sites (9.3 vs. 2.8 ppm, ash weight). However, they also found no significant difference between average cadmium content in on-road and off-road samples of cedar trees from 16 locations elsewhere in Missouri off the ore truck routes.

Table 2.17 and Figure 2.9 summarize cadmium concentrations in Spanish moss (Tillandsia usenoides) from eight states along the Atlantic and Gulf coasts in a U.S. Geological Survey study (Shacklette, 1972). Samples having extremely high cadmium content (above 20 ppm in ash) were from Limona and Panama City, Florida; Natchez, Mississippi; and East Baton Rouge Parish, Louisiana. These areas were considered to be affected by considerable industrial and automotive contamination. Low cadmium concentrations (less than 5 ppm in ash) were found in samples from areas where minimal airborne cadmium pollution is expected, such as Paradise Key, Everglades Park in Florida, and Monticello, Mississippi.

Distributions of cadmium in crops were studied in 19 states east of the Rocky Mountains by Huffman and Hodgson (1973). As shown in Table 2.18, the cadmium content in wheat and perennial grasses was relatively low, with less than 0.5 ppm in ash weight. They found no distinct geographic pattern for observed cadmium concentration.

Crops Grown on Sludge-Treated Land

The application of sewage sludge to croplands and the potential uptake of cadmium by food crops is a matter for concern. In 1976, EPA commissioned 30 scientists from the Council for Agricultural Science and Technology (CAST) to develop a state-of-the-art concensus on the application of sludge to croplands as it relates to heavy metal activity, including cadmium. Land disposal offers the opportunity of utilizing the fertilizer value of sludge, if there are not adverse effects from its metals content. the CAST study reports that metal levels may be a principal factor in determining acceptable rates of application of sludge to land, and cadmium is one of the metals governing the utilization of sludge. Repeated applications of sludge to land may lead to undesirable concentrations of cadmium in crops.

The chemistry of cadmium in soils is not yet well understood, but its lability in soil is reduced by organic matter, clay, hydrous iron oxides, high pH, and reducing conditions. The CAST committee identified the following land management options which can minimize the mobility of cadmium in soil/sludge or which can minimize the concentration in food plants. These include: (1) maintenance of soil pH at 6.5 or above; (2) choice of crops which accumulate relatively low concentrations of cadmium; (3) making only small annual sludge applications when food crops are to be

TABLE 2.17. CADMIUM LEVELS IN SPANISH MOSS, TILLANDSIA USNEOIDES[a]

Location	Concentration, ppm[b]	
	Ash Weight	Dry Weight[c]
Alabama		
Baldwin County, beach at Josephine	5.2	0.23
Cirrington County, 11.2 km (7 mi) west of Opp	3.4	0.15
Lowndes County, 4.8 km (3 mi) south of Letohatchee exit U.S. 65	4.4	0.20
Florida		
Bay County, Panama City	23.0	1.04
Broward County, Ft. Lauderdale	3.0	0.14
Collier County, Coximba area, Marco Island	4.3	0.19
Dade County, Paradise Key, Everglades	2.0	0.09
Dixie County, Cross City	4.8	0.22
Hillsboro County, Limona	25.0	1.13
Indian R. County, Vero Beach	2.2	0.10
Jefferson County, Monticello	15.0	0.68
Palm Beach County, West Palm Beach	2.0	0.09
Georgia		
Emanuel County, 4.8 km (3 mi) west of Stillmore	13.0	0.59
Lowndes County, 3.2 km (2 mi) north of Valdosta	13.0	0.59
Louisiana		
East Baton Rouge Parish	21.0	0.95
Franklin Parish, 1.6 km (1 mi) northeast of Winnsboro	3.6	0.16
Point Coupee Parish, near Batchelor	19.0	0.86
Tangipahoa Parish, Robert	3.6	0.16
Terrebonne Parish, Gibson	5.0	0.23
Vernon Parish, Rt. 8 at Sabine River Bridge	4.2	0.19
Mississippi		
Adams County, Natchez	27.0	1.22
Hinds County, 3.2 km (2 mi) south of Jackson	13.0	0.59
Lawrence County, 9.6 km (6 mi) south of Monticello	2.0	0.09
Walthall County, Rt. 27 at state line	4.8	0.22
Yazoo County, 9.6 km (6 mi) west of Yazoo	16.0	0.72
North Carolina		
Onslow County, Verna	17.0	0.77
Washington County, 12.8 km (8 mi) east of Roper	19.0	0.86
South Carolina		
Beauford County, Hunting Island State Park	5.2	0.23
Charleston County, Charleston	13.0	0.59
Dillon County, near Latta	14.0	0.63
Florence County, near Lake City	14.0	0.63
Georgetown County, Georgetown	4.2	0.19
Texas		
Fort Bend County, Sugar Land	15.0	0.68
Harris County, 8.0 km (5 mi) east of I-16 and I-10 junction	14.0	0.63
Jasper County, 1.6 km (1 mi) east of Neches River on Rt. 190	4.6	0.21
Jefferson County, Beaumont	13.0	0.59
Polk County, 1.6 km (1 mi) east of San Jacinto	3.8	0.17

---

[a] Source: Shacklette, 1972.

[b] Data taken from 123 locations in eight states during the period 1965-1970; 122 samples were analyzed.

[c] Converted from ash weight using geometric mean of ash in percentage of dry weight, 4.5 (ppm dry weight = ppm in ash x 0.045).

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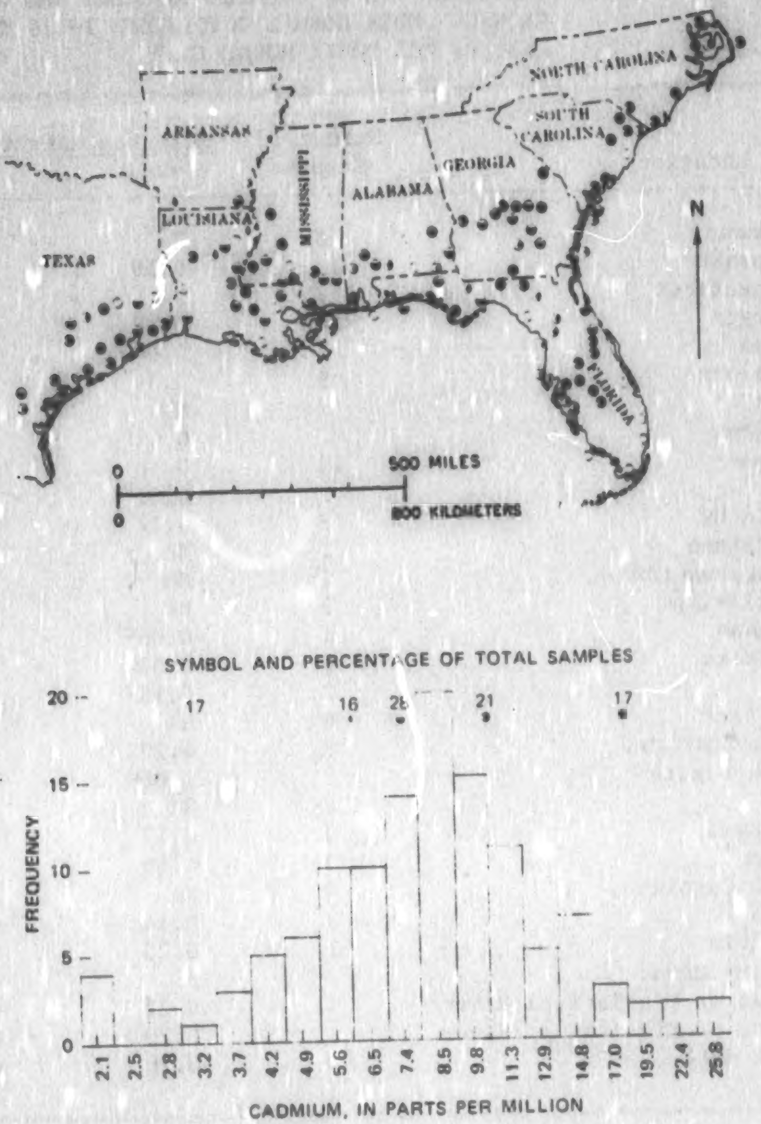


Figure 2.10. Localities of Spanish moss samples, and cadmium concentrations found in these samples (Shacklette, 1972).

TABLE 2.18. CONCENTRATION OF CADMIUM IN WHEAT AND GRASS GROWING UNDER NORMAL CONDITIONS IN 19 STATES EAST OF THE ROCKY MOUNTAINS[a]

Location	Number of Samples	Mean Concentration, ppm	
		Wheat	Grass
Alabama	8	NA[b]	0.17
Colorado	11	0.19	0.27
Connecticut	7	NA	0.13
Georgia	24	0.18	0.16
Idaho	2	0.04[c]	
Illinois	9	0.34	0.21
Iowa	7	NA	0.26
Indiana	2	0.03[c]	
Kansas	13	0.16	0.15
	1	0.01[c]	
Kentucky	3	0.12	0.11
Louisiana	1	NA	0.18
Massachusetts	7	NA	0.13
Mississippi	2	NA	0.44
Montana	1	0.06[c]	
Nebraska	8	0.32	0.25
	2	0.13[c]	
New York	6	NA	0.14
North Carolina	8	0.22	0.20
North Dakota	3	0.06[c]	
Ohio	8	NA	0.17
Oklahoma	3	0.12	0.14
Oregon	3	0.05	
South Carolina	4	NA	0.18
Texas	23	0.14	0.15
Virginia	1	0.25	NA
Summary Data:			
East of Mississippi River		0.22	0.17
West of Mississippi River		0.20	0.18
All data		0.20	0.17

---

[a] Source: Huffmann and Hodgson, 1973. Measurements were made in 1969 and 1970.

[b] Not available.

[c] Source: D. R. Buhler, 1976 (unpublished data).

grown; (4) use of sludges low in cadmium on croplands; and (5) growth of nonedible crops, e.g., biomass or fiber crops, on sludge-treated lands.

Sludge has a tendency to lower soil pH, and cadmium uptake by plants is higher in acid soils, so pH control is a fundamental requirement for proper management of sludge-treated soils. Numerous investigators have studied the effect of pH on cadmium uptake by various plants. Data presented by Chaney and Hornick at the first International Cadmium Conference in February, 1977, illustrate the pH effect very well (Figure 2.10). These data show a decline in the cadmium content of soybean leaves as the soil pH is increased to near neutrality. Figure 2.10 also shows the significant effect of increasing the cadmium concentration of the soil. However, other work involving repeated annual applications of sludge to soil cropped to corn show that the amounts applied in a given year influence the cadmium uptake to a greater extent than the total cumulative amounts of cadmium applied (CAST, 1976). The proper management involves not only the use of sludges low in cadmium on croplands, but the making of only small sludge applications each year.

Another important consideration is the fact that crops differ greatly in the ability to take up cadmium. The cadmium contents of a variety of crops grown on sludge-treated soil containing 10 ppm of cadmium are given in Table 2.19. The leafy vegetables in these studies were high in cadmium content (e.g., 161 ppm for spinach), whereas the edible portions of grains such as corn and rice were low (less than 1 or 2 ppm). The same crops grown on control soil containing only 0.1 ppm of cadmium exhibited significantly lower cadmium contents.

It has also been suggested that rates of application of sludge should be limited by the ratio of cadmium to zinc in the sludge. A cadmium concentration below 1 percent that of zinc is advocated in the EPA Draft Document on Acceptable Methods for the Utilization or Disposal of Sludges (U.S. Environmental Protection Agency, 1974). One premise for this concept is that it would result in high enough zinc concentrations in soil to kill plants before cadmium could accumulate to levels in foods considered hazardous to animals and humans (CAST, 1976). However, the CAST committee cautions that this premise often is not correct, and they advocate that the concept be abandoned or used only in combination with other criteria.

Invertebrates

Little information has been documented on the cadmium content in terrestrial invertebrates even though they play an important role in the vertical transport of trace elements in the environment (Table 2.20).

Gish and Christensen (1973) found that cadmium concentrations in earthworms along the Baltimore-Washington, D.C., Parkway were approximately ten times the cadmium levels in the soil (6.9 to 12.6 ppm in worms vs. 0.68 to 1.2 ppm in soil). The earthworms near the highway seemed to have a higher concentration of cadmium than those further from the road. In Tennessee, Anderson et al. (1974) found approximately 17 times more cadmium

TABLE 2.19. CADMIUM CONTENT OF CROPS GROWN IN THE GREENHOUSE ON CALCAREOUS DOMINO SILT LOAM WITH AND WITHOUT SEWAGE SLUDGE TREATMENT[a]

	Cadmium per Gram of Dry Plant Tissue, µg			
	Control Soil[b]		Sludge-Treated Soil[c]	
Crop	Diagnostic Leaf	Edible Tissue	Diagnostic Leaf	Edible Tissue
Paddy rice	<0.1	<0.1	<0.1	0.2
Upland rice	0.4	<0.1	0.9	0.4
Sudangrass	0.2	0.2	5.7	5.7
White clover	0.2	0.2	6.0	6.0
Alfalfa	0.3	0.3	8.2	8.3
Bermudagrass	0.3	0.3	9.4	9.4
Field bean	0.6	<0.1	10.3	0.7
Wheat	<0.1	<0.1	11.6	5.8
Zucchini squash	0.6	<0.1	12.5	0.7
Soybean	0.4	0.7	15.6	10.7
Tall fescue	1.4	1.4	17.3	17.3
Corn	3.9	<0.1	27.0	1.4
Carrot	1.4	0.9	38.0	16.0
Cabbage	0.7	0.2	39.0	1.8
Radish	4.2	0.3	40.0	4.0
Swiss chard	1.4	1.4	42.0	42.0
Table beet	0.8	0.2	47.0	4.5
Romaine lettuce	0.8	0.8	62.0	62.0
Tomato	2.6	<0.1	71.0	2.4
Curlycress	2.4	2.4	89.0	89.0
Spinach	3.6	3.6	161.0	161.0
Turnip	1.8	<0.1	162.0	9.2

[a] Source: Bingham et al., 1975, 1976; CAST, 1976.

[b] Domino silt loam containing 0.1 ppm of Cd.

[c] Sludge treated with cadmium sulfate to supply 10 µg of cadmium per gram of soil. The sludge was added at the rate of 10 g per kg of soil.

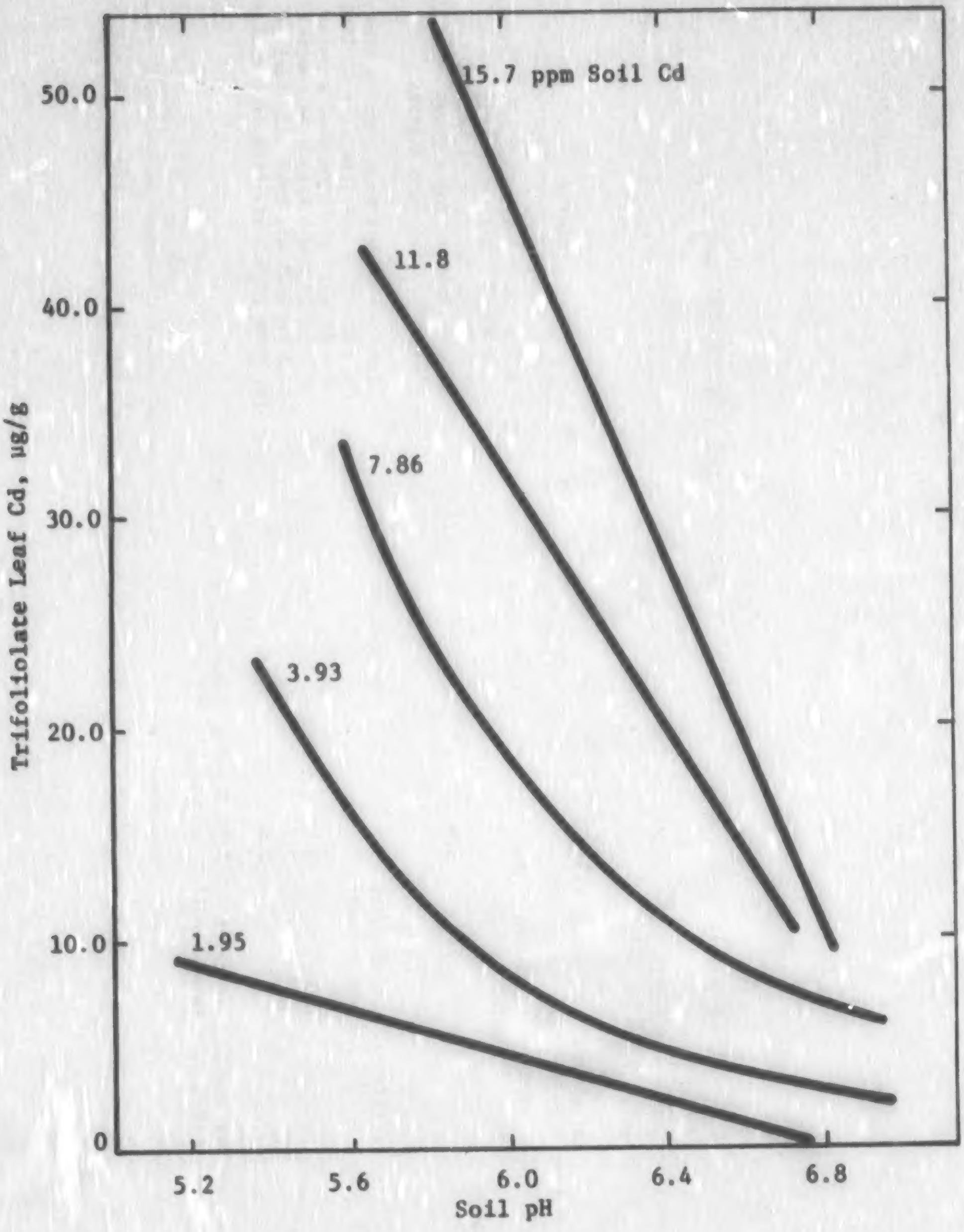


Figure 2.10. The effect of soil pH and cadmium concentration on the cadmium content of soybean leaves (Chaney and Hornick, 1977).

TABLE 2.20. LEVELS OF CADMIUM IN TERRESTRIAL INVERTEBRATES

Location	Date of Data Collection	Organism	Concentration, ppm dry weight Mean	Concentration, ppm dry weight Range	Reference	Remarks
Maryland Highway 1 and Baltimore-Washington Parkway	1970	Earthworm (whole body)	12.6		Gish & Christensen, 1973	3.1 m (10 ft) from highway
			8.8			6.1 m (20 ft) from highway
			8.3			12.2 m (40 ft) from highway
			6.9			24.4 m (80 ft) from highway
			7.1			48.8 m (160 ft) from highway
Montana Deer Lodge Valley	1970	Grasshoppers (whole body)	5.0		Munshower, 1972	4.0 km (2.5 mi) from zinc smelter
			2.1			24.1 km (15.0 mi) from zinc smelter
			2.7			5.6 km (3.5 mi) from zinc smelter
			5.2			6.1 km (3.8 mi) from zinc smelter
			2.2			14.5 km (9.0 mi) from zinc smelter
			0.4			201.1 km (125.0 mi) from zinc smelter
Tennessee, East	Not available	Earthworm (whole body)	5.7	3.1-9.3	Anderson et al., 1974	

in earthworms (5.7 ppm dry weight) than in soil (0.35 ppm). Grasshoppers in Montana contained slightly higher cadmium concentrations than their food (Munshower, 1972).

Mammals

Data pertaining to cadmium levels in terrestrial mammals are available from locations in eight states (Figure 2.11). No national or comprehensive regional monitoring program exist. Many of these studies are related to highly contaminated regions and none was continued for a period long enough to allow trends to be established.

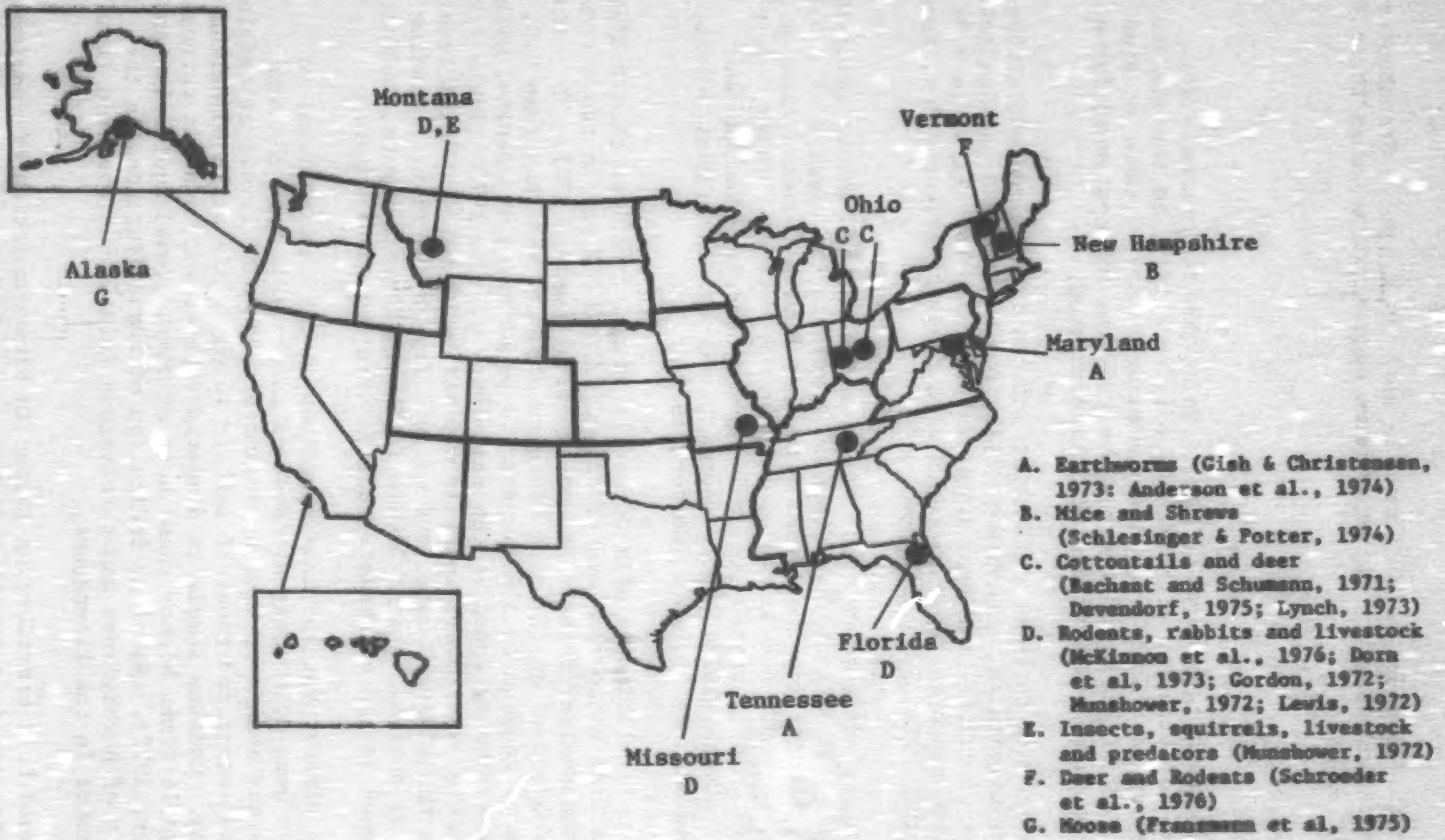
There appears to be no difference between cadmium concentrations in domestic and wild animals. Munshower (1972) found that mean cadmium levels in the kidneys of cattle from Deer Lodge Valley in Montana (1.67 to 3.04 ppm) were in the same range as those in their wild counterparts--red fox, badger, and ground squirrel (1.35 to 3.47 ppm).

More marked differences were shown in the cadmium values found in domestic rabbits and cottontails. Cadmium levels in the kidneys of rabbits from Missoula, Montana (control), and from East Helena, Montana (near a lead smelter), were 0.3 and 35.6 ppm, respectively (Gordon, 1972). Cottontail rabbits in Ohio contained 1.3 to 1.6 ppm of cadmium (Bachant and Schumann, 1971; Lynch, 1973), while mountain cottontails in East Helena, Montana, had as high as 53.0 ppm (Gordon, 1972).

Cadmium levels in the milk of cattle ranged from less than 0.0005 ppm in samples from Missouri (Dorn et al., 1973) to 0.2 ppm in those from an area near the smelter in East Helena, Montana (Lewis, 1972). The cadmium content in the blood of cattle from southern Missouri was less than 0.01 ppm. Concentrations of cadmium in blood appear to be affected by seasons, with the highest levels being found in the fall (Dorn et al., 1973) (Table 2.2.). However, in cattle as in other domestic and native animals, cadmium levels are highest in the kidneys, hair, and secondarily in the liver. Cadmium levels are at or near background levels in other internal organs, indicating that these organs do not accumulate cadmium from the environment.

Unlike plants, the species-dependency of the cadmium level in animals has not been demonstrated. Most of the animals from the same geographical areas seemed to have approximately the same levels of cadmium in their bodies except for those of rabbits found in the polluted Helena Valley, Montana. Cadmium levels in domestic rabbits and mountain cottontails were 7 to 16 times higher than those of cows, ground squirrels, and mice (Munshower, 1972). No clear indication of any differences in the cadmium content of herbivorous and carnivorous animals was observed from the data presented in the literature.

Age could be a contributing factor in bioaccumulation of cadmium in animals. Mature ground squirrels and gray squirrels had about 4 to 5 times greater cadmium concentrations than their immature counterparts (Munshower,


Montana
D,E
Vermont
F
Ohio
C C
New Hampshire
B
Maryland
A
Alaska
G
Florida
D
Tennessee
A
Missouri
D

A. Earthworms (Gish & Christensen, 1973: Anderson et al., 1974)
B. Mice and Shrews (Schlesinger & Potter, 1974)
C. Cottontails and deer (Bachant and Schumann, 1971; Devendorf, 1975; Lynch, 1973)
D. Rodents, rabbits and livestock (McKinnon et al., 1976; Dorn et al, 1973; Gordon, 1972; Munshower, 1972; Lewis, 1972)
E. Insects, squirrels, livestock and predators (Munshower, 1972)
F. Deer and Rodents (Schroeder et al., 1976)
G. Moose (Franzmann et al, 1975)

Figure 2.11. Locations of study areas for cadmium levels in terrestrial animals, excluding birds.

TABLE 2.21. CADMIUM LEVELS IN CATTLE[a,b]
(ppm, dry weight)

	1971		1972				1973	
Organ	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer
Blood	0.0174	0.0038	0.0060	0.0076				
	0.0216[a]	0.0038	0.0080	0.0036				
Milk	0.0030	0.0042	0.0030	0.0020				
	0.0043	0.0040	0.0030	0.0030				
Hair					1.29	1.74	2.80	0.67
					0.06	0.13	0.05	0.04

	1971-1972
Liver	0.90
	0.24
Kidney	3.70
	1.40
Diaphragm	0.10+
	0.10+

---

[a] Note each number pair in table. Top number represents environmentally exposed animals--bottom number represents controls.

[b] Source: Dorn et al., 1973.

1972; McKinnon et al., 1976). However, in most cases, the ages of animals studied were not known.

Birds

Data on cadmium levels in birds from national monitoring programs are limited to starlings collected at 56 sites from 44 states (Figure 2.12) during 1971 (Martin and Nickerson, 1973) and 1973 (White et al., 1976). The levels of cadmium for both years ranged from less than 0.05 ppm to 0.2 ppm, but a light increase in overall values was observed in 1973 (Table 2.22). In 1971, 32 of the 50 samples contained less than 0.05 ppm, with only 14 samples exceeding 0.05 ppm. In 1973, however cadmium levels in 21 of 51 samples were higher than 0.05 ppm, with 18 samples being less than 0.05 ppm. Cadmium levels at all 6 sites which had more than 0.1 ppm during 1971 dropped to less than 0.07 ppm in 1973, while the concentrations in 6 other sites were nearly doubled from less than 0.06 ppm in 1971 to more than 0.11 ppm in 1973. Locations where more than 0.1 ppm of cadmium was found in starlings were Phoenix, Arizona; Stuttgart, Arkansas; Bakersfield, California; Farmington, New Mexico; and Elkins, West Virginia, in 1971; and Brighton, Colorado; Evansville, Indiana; Gary, Maine; Malden, Missouri; Pittsburgh, Pennsylvania; and Salt Lake City, Utah, in 1973.

Lynch (1973) conducted a statewide study on cadmium levels in ring-necked pheasants in Ohio and found that the mean cadmium level in kidneys was 7.45 ppm, while edible portions, leg and breast muscle, contained 0.08 to 0.17 ppm, respectively.

Studies of the common tern from Long Island, New York, and from Hamilton, Lake Ontario, failed to show any significant differences in cadmium in the kidneys, 21.3 to 29.5 ppm (Connors et al., 1975). Brown pelicans from California had much higher cadmium in the liver than those from Florida, but the cadmium level in other parts of the body (breast and bone) were in the same range for both groups (Fleischer et al., 1974). The highest cadmium concentration reported from birds, 53.2 ppm, was found in the ashy petrel from the California coast (Anderlini et al., 1972).

Comparisons between ecologically equivalent species or different species occupying the same locality were possible for the ring-necked pheasant and mourning dove from Ohio. The breast muscle of mourning doves had much higher concentrations of cadmium than the ring-necked pheasants. This may be attributed to a number of factors, including migratory behavior and the kinds of food eaten.

AQUATIC BIOTA

Plants and Algae

In a study of the environmental flow of cadmium and other trace metals in northwestern Indiana, Yost et al. (1974) found that filamentous

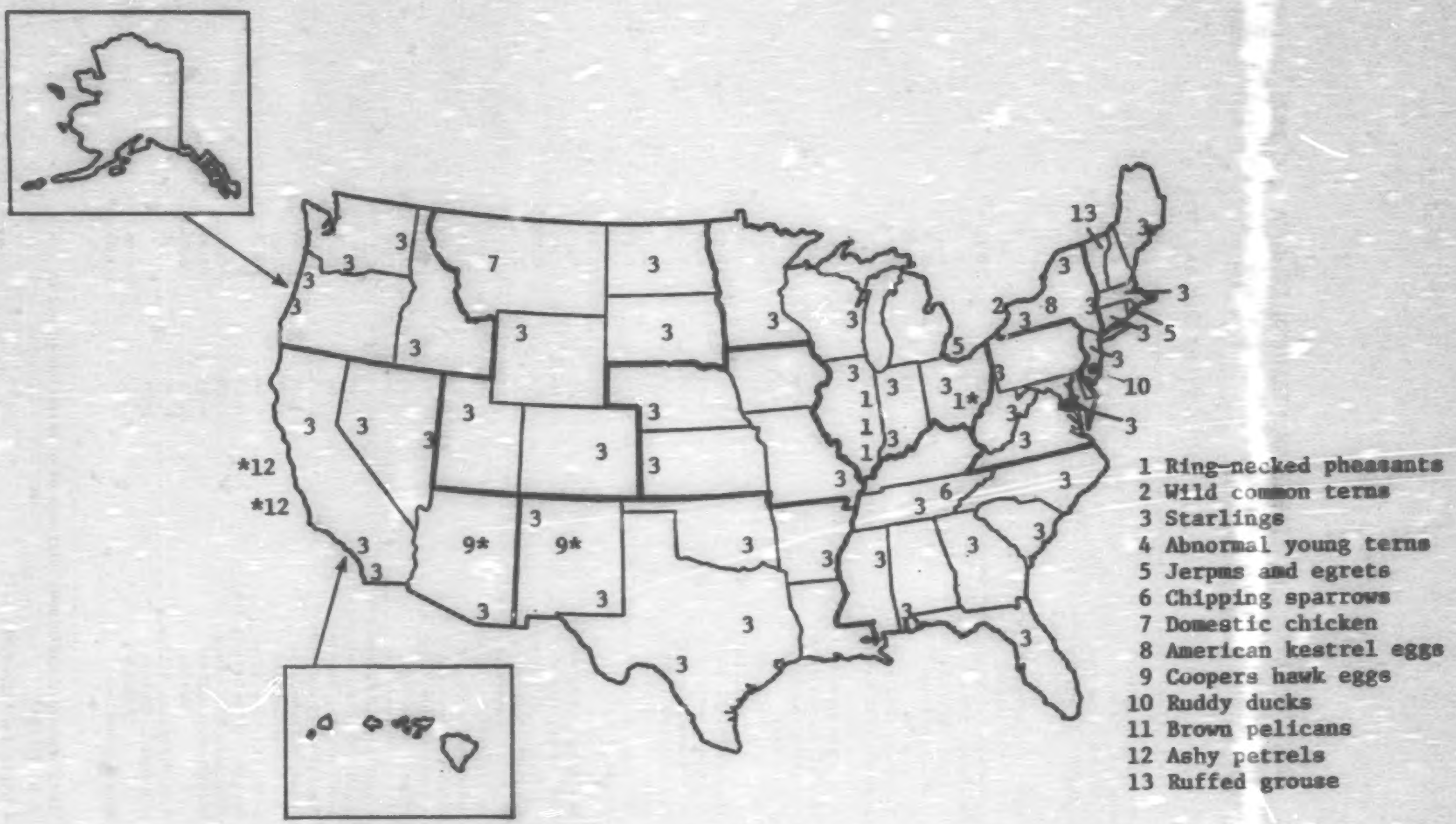

1 Ring-necked pheasants
2 Wild common terns
3 Starlings
4 Abnormal young terns
5 Jerpms and egrets
6 Chipping sparrows
7 Domestic chicken
8 American kestrel eggs
9 Coopers hawk eggs
10 Ruddy ducks
11 Brown pelicans
12 Ashy petrels
13 Ruffed grouse
*12
*12
9*
9*
1*

Figure 2.12. Locations for cadmium sampling in birds.
[*Exact location(s) in state not indicated.]

TABLE 2.22. CADMIUM LEVELS IN STARLINGS MEASURED IN 1971 and 1973[a]

	Concentration, ppm wet weight	
	1971[b]	1973[c]
Alabama, Mobile	<0.05	<0.05
Arizona, Phoenix	0.11	0.05
Arkansas, Stuttgard	0.10	<0.05
California, Bakersfield	0.18	0.09
Los Angeles	0.06	0.05
Sacramento	<0.05	<0.05
Colorado, Brighton		0.12
Greeley	0.05	
Connecticut, Connecticut River Valley	<0.05	<0.05
Delaware, Dover	0.09	
Florida, Gainesville	<0.05	0.05
Georgia, Atlanta	<0.05	0.09
Idaho, Boise	<0.05	0.08
Illinois, Chicago	0.06	<0.05
Indiana, Evansville	<0.05	0.12
Gary		0.07
Iowa, Des Moines		<0.05
Kansas, Garden City	0.05	0.07
Louisiana, Baton Rouge	<0.05	0.09
Maine, Gray	<0.05	0.10
Maryland, Patuxent	<0.05	0.08
Annapolis		0.05
Massachusetts, Quincy	<0.05	<0.05
Michigan, Lansing	0.12	0.06
Minnesota, Twin Cities	0.08	0.05
Mississippi, Starkville	<0.05	<0.05
Missouri, Malden	<0.05	0.13
Nebraska, North Platte	<0.05	0.05
Nevada, McGill	<0.05	<0.05
Reno	<0.05	<0.05
New Jersey, Brunswick	<0.05	0.06
New Mexico, Carlsbad	<0.05	<0.05
Farmington	0.11	0.05
New York, Albany		0.08
Jamestown	0.08	<0.05
North Carolina, Raleigh	<0.05	0.05
North Dakota, Bismarck		0.09
Ohio, Columbus	0.08	0.05
Oklahoma, Tishomingo	<0.05	<0.05
Oregon, Corvallis	<0.05	0.06
Wilsonville	0.09	0.07
Pennsylvania, Pittsburgh	<0.05	0.11
South Carolina, Columbia	<0.05	
South Dakota, Pierre	<0.05	<0.05
Tennessee, Nashville	<0.05	0.05
Texas, Hillsboro	<0.05	<0.05
San Antonio	<0.05	<0.05
Utah, St. Lake City	0.06	0.20
Vermont, Champlain Valley	<0.05	
Virginia, Blacksburg	<0.05	0.05
Washington, Spokane	<0.05	<0.05
Yakima	<0.05	0.05
West Virginia, Elkins	0.12	0.07
Wisconsin, Horicon	<0.05	
Portage		0.06
Wyoming, Worland		0.05

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[a] Data represent whole body analysis of a composite sample of ten starlings.

[b] Martin and Nickerson, 1973.

[c] White et al., 1976.

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algae had relatively higher concentrations of cadmium, with mean values up to 2.33 ppm, than rooted plants. Other aquatic plant samples contained less than 1.0 ppm cadmium.

Aquatic plants from the more heavily contaminated area of the Coeur d'Alene-Spokane River drainage system showed high concentrations of cadmium in their tissues. Funk et al. (1973) measured cadmium levels from 30 to 270 ppm in algae, mainly Cladophora sp., indicating the ability of algae to concentrate cadmium by factors of 10^2 to 10^3 in relation to water. Submergent or emergent aquatic plants from Foundry Cove in the Hudson River near a nickel-cadmium battery plant were found to contain concentrations of cadmium averaging up to 89.4 ppm, with a range from 1.8 to 269 ppm in their leaves and stems. The roots of Spartina grass from the same area exhibited a mean cadmium content of 1,100 ppm (range 247 to 2,960 ppm), whereas the cadmium content in their leaves averaged only 13.6 ppm (Kneip et al., 1975).

Marine algae in southern California showed relatively higher concentrations (with maximum levels up to 20.9 ppm) than the algae from the northern coast, reflecting the cadmium contamination of the San Diego area (Martin and Broenkow, 1975).

Invertebrates

Comparison of data on cadmium levels in aquatic invertebrates with those for fish indicate a much greater concentration of cadmium in invertebrates. In general, the distribution of elevated cadmium levels in invertebrates is more uniform than in fish. Elevated levels were found most often in whole organisms rather than in muscle tissue. The highest levels (5 ppm) in Atlantic oysters were from the Housatonic River, Connecticut. Levels greater than 2 ppm were found in scallops from Cape Kennedy, Florida; green abalone from San Diego, California; and Pacific oysters from Puget Sound (National Marine Fisheries Service, 1975).

In one of many local studies, Fleischer et al. (1974) indicated that cadmium levels in marine invertebrates from unpolluted areas were in the range 0.4 to 2.6 ppm (dry weight). Cadmium levels greater than 1 ppm were found in clam, oyster, and scallop specimens from Long Island Sound, New York; Cape Canaveral, Florida (Zook et al., 1976); West Bay and Nueces Bay, Texas (Roberts et al., 1975); and the southern California coast (Vattuone et al., 1976); probably reflecting higher cadmium levels in these waters. Cadmium content in most of the commercial shrimp was less than 0.1 ppm, except those in Trinity Bay, Texas (0.22 ppm). Mean cadmium concentrations in oysters appeared to reflect the degree of industrialization in the estuary in which they lived (Figure 2.13).

Marine zooplankton exhibited higher cadmium content than those from freshwater. Freshwater zooplankton from Lake Michigan and vicinity had average values greater than 0.4 ppm cadmium (Mathis and Kevern, 1973; Martin and Broenkow, 1975), while marine zooplankton from southern California waters had maximum levels up to 15.2 ppm and those from the northern

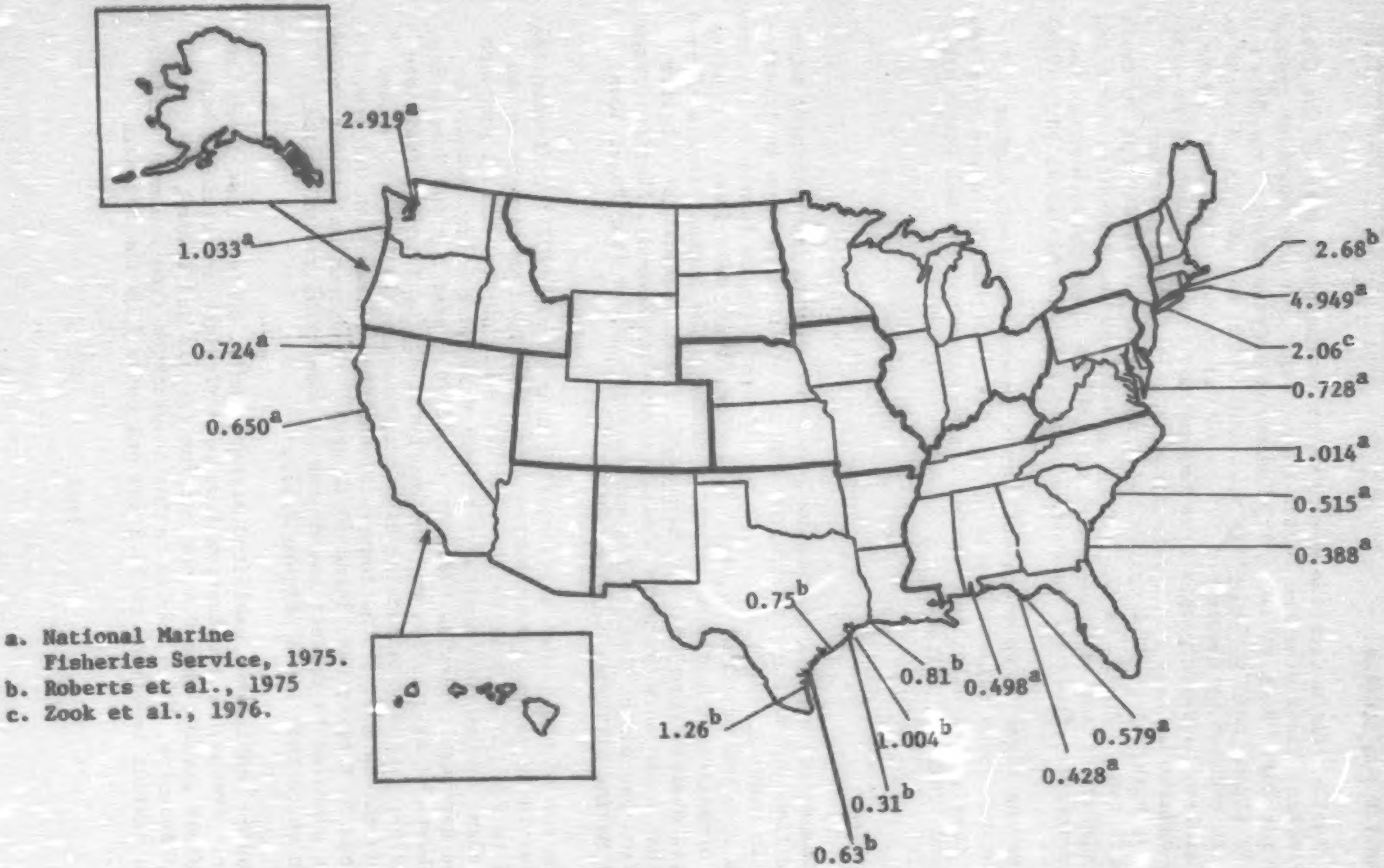

2.919a
1.033a
0.724a
0.650a
2.68b
4.949a
2.06c
0.728a
1.014a
0.515a
0.388a
0.75b
0.81b
0.498a
0.579a
0.428a
1.26b
1.004b
0.31b
0.63b
a. National Marine Fisheries Service, 1975.
b. Roberts et al., 1975
c. Zook et al., 1976.

Figure 2.13. Mean cadmium concentrations (ppm) in Atlantic and Gulf of Mexico oysters (*Crassostrea virginica*) and Pacific Ocean oysters (*C. gigas*).

California and Oregon coasts about 6.2 ppm. Martin (1970) reported that the cadmium concentration factor for zooplankton was approximately 6,000 times that in water. This high concentration level was not common in most of the zooplankton studied.

Cadmium levels in tubificid worms (Oligochaeta) varied greatly, ranging from 1.1 ppm for worms in the Illinois River at Peoria (Mathis and Cummings, 1973) to 230 ppm for those from the Palestine Lake in Indiana (Yost et al., 1975). Oligochaete worms from highly contaminated water of the Spokane River in Idaho contained a comparatively lower level of 4.3 ppm cadmium, while other bottom-dwelling invertebrates such as midges, mayfly larvae, and snails concentrated cadmium up to 97 ppm (Funk et al., 1973).

Fish

Fish are the most widely studied species among all aquatic organisms and numerous local and/or statewide studies have been made throughout the United States. The National Pesticide Monitoring Program compiled cadmium levels in freshwater fish from 92 rivers and streams in 46 states, but data are available only for 1972. From most of the rivers studied, cadmium concentrations were within the range of less than 0.05 to 0.5 ppm with only those from 10 rivers exceeding this limit. A maximum cadmium level of greater than 1 ppm was found in fish collected from the Sacramento River in California, Connecticut River in Connecticut, Wabash River in Indiana, Yazoo River in Mississippi, and Columbia River in Washington. The highest cadmium level recorded was 1.7 ppm in a northern squawfish from the Columbia River, Washington. Other high values (greater than 1.0 ppm) typically occurred in carp, suckers, and other bottom feeders.

The cadmium levels in the muscle or whole body of most freshwater fish found in the localized studies were less than 0.1 ppm with a few exceptions. Fish from Palestine Lake, Indiana, contained more than 0.5 ppm in the muscle (Atchison, 1975). Mean cadmium residues in trout from Climax Colorado, were relatively higher, reaching up to 4.2 ppm in muscle (Roberts et al., 1975). Cadmium concentrations in fish from Foundry Cove in the Hudson River, New York, were highest of all, averaging 9.1 to 12.3 ppm (Schroeder, 1974). Of the organs surveyed in a study by Roberts et al. (1975), bone and liver tissues of freshwater fish consistently showed highest levels of cadmium (Table 2.23). Values in bone ranged as high as 46.6 ppm, liver to 25.9 ppm, in these contaminated fish, where muscle tissue cadmium concenterations were as high as 4 ppm. These data show some indication of a reduced cadmium burden in the trout of these areas over the 3 years of the study (Roberts et al., 1975).

Cadmium levels appeared to be lower in marine and estuarine fish than in the freshwater fish. Data from the NMFS Microconstituent Resource Survey indicate elevated concentrations in fish generally along the southern Atlantic and the Pacific coastlines of the U.S. Highest concentrations (greater than 0.2 ppm) were found in analyses of whole fish, mainly menhaden and ballyhoo. High concentrations (greater than 0.1 ppm) in muscle tissue

TABLE 2.23. FRESHWATER FISH--CADMIUM LEVELS IN TISSUES[a]

Organ	Species	Location	Mean Concentration, ppm 1969	1970	1971
Bone	Brook trout	Climax area, CO	20.3[b]		
	Brown trout	"	26.4[b]		
	"	"		8.2[b]	
	Rainbow trout	"		4.0	
	Brook trout	"			6.0
	Brown trout	"			1.6
	Rainbow trout	"			7.8
	Brown trout	Lake City, CO	8.9		
	Brook trout	"			0.0
	Brown trout	"			2.5
	Rainbow trout	"	2.8		
	Brook trout	Silverton area, CO	11.3		
	Rainbow trout	"	19.9		
	Brook trout	"		13.1	
	Rainbow trout	"		8.1	
	Brook trout	"			4.0
	"	"			1.7
Muscle	Brook trout	Climax area, CO	3.1		
	Rainbow trout	"	3.3		
	Brook trout	"		1.2	
	Brown trout	"		1.2	
	Brook trout	"			0.0
	Brown trout	Lake City, CO	4.2		
	"	"			0.0
	Brook trout	Silverton area, CO			1.1
Liver	Brook trout	Climax area, CO		13.5[b]	
	Rainbow trout	"		1.1	
	Brook trout	"			7.7[b]
	"	"			7.0
	Rainbow trout	"			2.1
	Brown trout	Lake City, CO	0.0		
	Brook trout	"			4.5
	Brown trout	"			8.1
	Rainbow trout	Silverton area, CO	2.6		
	Brook trout	"		4.2	
	Rainbow trout	"		7.4	
	Brook trout	"			0.0
	"	"			0.4
Whole fish	Brook trout	Climax area, CO		6.5	
	Brown trout	"		3.0	
	Rainbow trout	"		3.0	
	Brook trout	"			0.0
	Brown trout	"			2.3
	Rainbow trout	"			2.7
	Brown trout	Lake City, CO			0.0

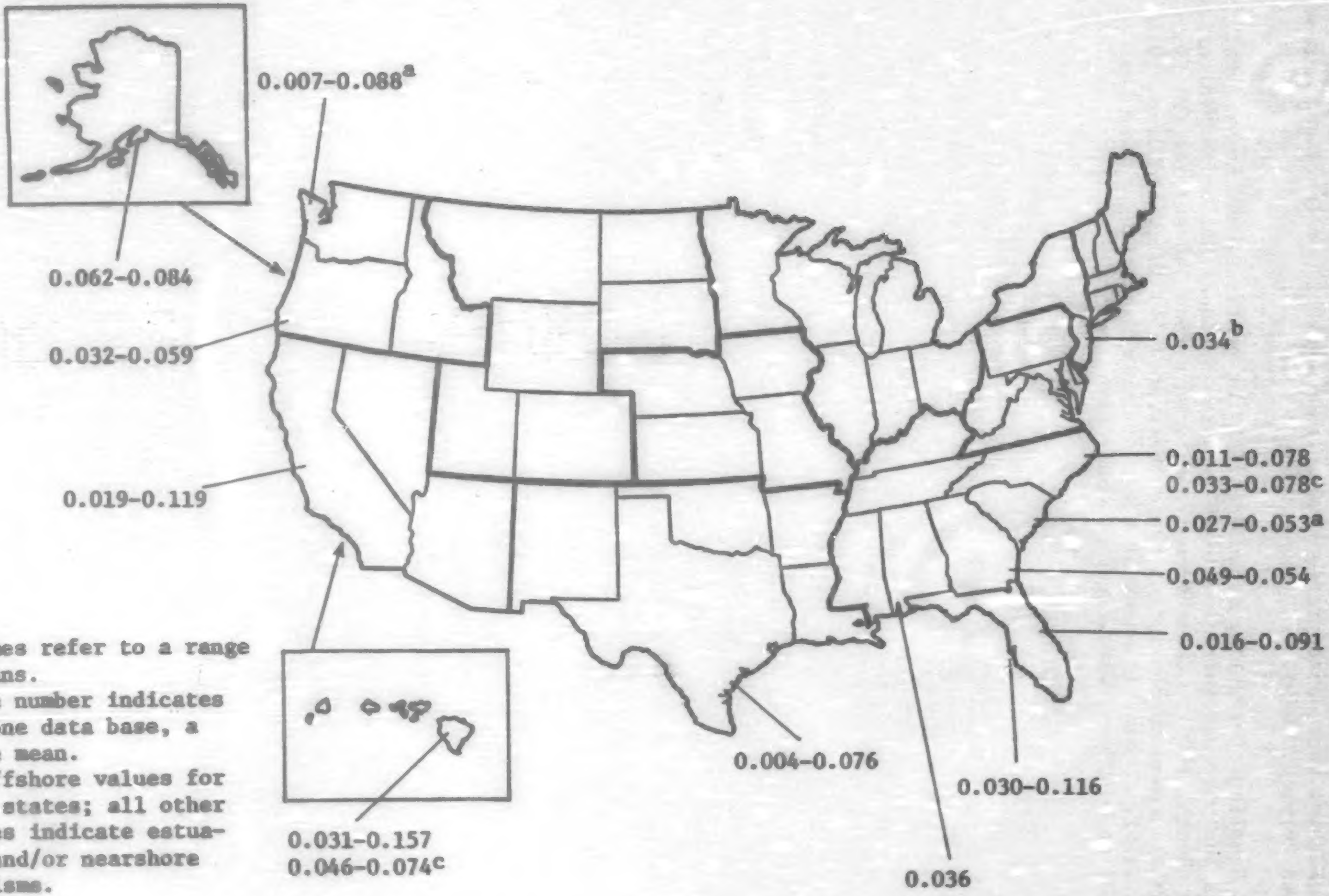
---

[a] Source: Roberts et al., 1975.

[b] Calculated value.

were found in blue marlin from Hawaii, petrale sole from Pidgeon Point, California, and Pacific bonita from Coronado Island, California (Figure 2.14). Highest mean concentrations were less than 0.2 ppm (National Marine Fisheries Service, 1975).

Sampling of yearling estuarine fish for pesticide and heavy metal residues analyses was initiated in 1972 by the National Estuarine Monitoring Program (Heath, 1976). Cadmium analyses of more than 540 samples (25 fish per sample) showed no consistent trends between July, 1972, and June, 1976 (Heath, 1976). Geometric means of the positive residue ranged from less than 0.02 to 0.15 ppm, wet weight of whole fish, for cadmium.


0.007-0.088[a]
0.062-0.084
0.032-0.059
0.019-0.119
0.031-0.157
0.046-0.074[c]
0.004-0.076
0.036
0.030-0.116
0.016-0.091
0.049-0.054
0.027-0.053[a]
0.011-0.078
0.033-0.078[c]
0.034[b]

[a] Extremes refer to a range of means.

[b] Single number indicates only one data base, a single mean.

[c] Far offshore values for those states; all other figures indicate estuarine and/or nearshore organisms.

Figure 2.14. Cadmium in marine fish--muscle tissue, ppm [data averaged among various species along whole coastline of indicated state (National Marine Fisheries Service, 1975)].

3. CADMIUM BEHAVIOR IN THE ENVIRONMENT

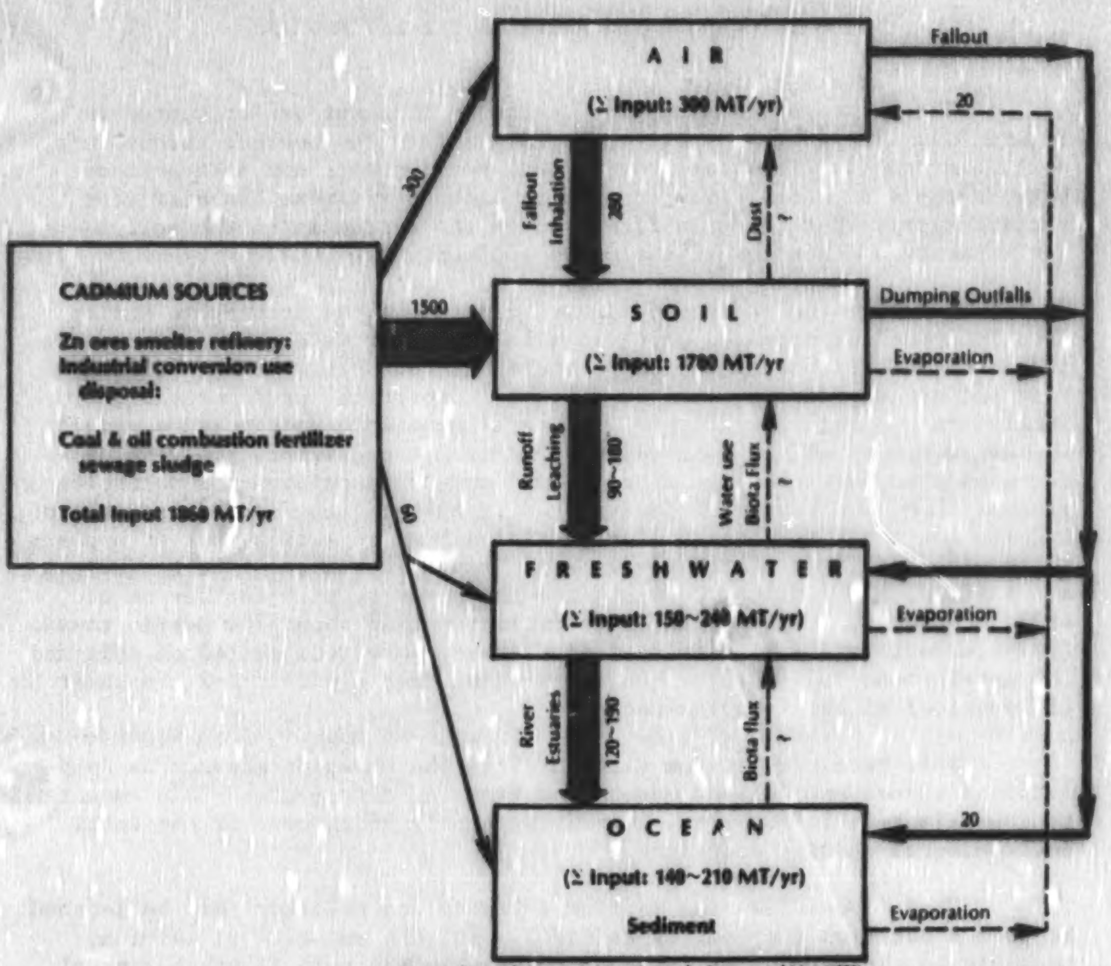
The routes of cadmium flow in the environment are presented in Figure 3.1. The diagram shows the pathways from the sources through air, soil, and aquatic (freshwater and ocean) environments and interactions between the ecosystems. The cadmium in each environment has different characteristics but the main flux through the system is to the soil environment and then toward the ocean sediment.

Although the residence time of cadmium in the atmosphere varies greatly depending upon the particle size and other meteorological factors, presumably the airborne cadmium particles are eventually returned to the land and aquatic environments by fallout, adsorption, agglomeration, or inhalation. A major fraction of the cadmium emission accumulates mainly in the proximity of the sources, varying from a negligibly small value for submicron particles to practically complete deposition for particles greater than 10 microns (Fleischer et al., 1974). Long-range transport of cadmium may occur for the smaller particles by wind action, but it appears to be within a limit of relatively small range, a radius of 16 km (Meisch and Huffman, 1972) or up to 24 km from the smelter stack (Bolter et al., 1975; Munshower, 1972). Thus it is estimated that about 254 metric tons (93.5 percent) of cadmium emitted into the air are redeposited on soil and 180 metric tons (6.5 percent) on surrounding oceans within a 22 km limit (12 nautical miles) from the shore.

Soil receives cadmium directly from the emission sources as land-destined wastes and fallout deposition from the atmosphere. This amounts to approximately 1,780 MT/yr, comprising nearly 96 percent of the total environmental cadmium emissions.

Upon deposition, the cadmium sulfates and chlorides may be leached or washed out from the soil by rainfall. But the majority of cadmium, possibly in the form of oxides, accumulates in the soil (Fleischer et al., 1974). Studies of cadmium transport in soil indicate that about 95 percent of cadmium introduced in soil is retained, while only 5 percent exists via the stream discharge (Andren et al., 1975; Huckabee and Blaylock, 1974).

Only a speculative estimate can be made for the cadmium flux from freshwater to the ocean due primarily to the lack of information on the sedimentation loss of cadmium in the freshwater environment. The rate of sedimentation of cadmium would be controlled largely by the rate and mode of river flows as well as by chemical and physical processes occurring in estuaries. When freshwater reaches the river-estuary boundary, cadmium associated with other organic materials tends to deposit rather rapidly



A I R
(Σ Input: 300 MT/yr)
Fallout
20
300
Fallout
Inhalation
280
Dust
?
CADMIUM SOURCES
Zn ores smelter refinery: industrial conversion use disposal:
Coal & oil combustion fertilizer sewage sludge
Total Input 1860 MT/yr
1500
S O I L
(Σ Input: 1780 MT/yr
Dumping Outfalls
Evaporation
Runoff
Leaching
90~180
Water use
Biota Flux
?
60
F R E S H W A T E R
(Σ Input: 150~240 MT/yr)
Evaporation
River
Estuaries
120~190
Biota flux
?
O C E A N
(Σ Input: 140~210 MT/yr)
Sediment
20
Evaporation

Data used are cadmium emission estimates by Sargent and Metz(1975):
Fluxes from air compartment based on the ratio of U.S. land (including inland waters) vs. seas (12- mile limit): 93.5 vs. 6.5;
Flux from soil compartment estimated cadmium net flux (output) as 5-10 percent of the total input;
Flux from freshwater based on net flux through river as 80 percent (20 percent sedimentation loss))

Figure 3.1. Environmental flow of cadmium emitted by man's activities.

due to increased salinity (Windom, 1976) and is thus confined to estuaries or to coastal waters.

Windom (1976) found that about 17 percent of cadmium is lost in the southeastern U.S. salt marsh environment through sedimentation, and the net flux of cadmium through the estuary was about 83 percent. Assuming that 80 percent net flux goes into the ocean environment, the cadmium delivered to the adjacent U.S. oceans each year would be about 120 to 190 metric tons, amounting to a total cadmium input of 140 to 210 MT/yr, including fallout.

AIR TRANSPORT

Cadmium in the atmosphere is mainly in the form of suspended aerosol particles as oxides, chlorides, or sulfates (Hise and Fulkerson, 1973). The size of particles varies considerably from submicron range to probably greater than 50 microns, with the mass median diameter (MMD) being 1.54 to 3.1 microns (Lee and von Lehmden, 1973). Particles 1.5 microns in diameter are the most abundant in fly ash (100 ppm), but much lower concentrations of cadmium (less than 5 ppm) are associated with particles larger than 3.5 microns. Lee and von Lehmden (1973) indicated that larger particles (greater than 50 microns) settle out very rapidly, and smaller ones remain airborne for longer periods and are transported to greater distances by wind or diffusion forces. Thus the concentrations and residence time of cadmium in the air increase markedly with decreasing particle size (Davison et al., 1974).

There are basically three phases of the air pollution cycle: (1) pollutant release from the source; (2) diffusion and transport of the contaminant within the atmosphere; and (3) removal of the pollutant from the air or the reception of the pollutant by animate and inanimate objects. Data on the behavior and the movement of cadmium particles in the atmosphere (2nd phase) are not yet available. Meteorological factors, such as wind (direction, velocity, advection), precipitation, air masses, and turbulence greatly influence this atmospheric pollutant cycle. Henmi and Reiter (1974) emphasized the role of clouds as an important factor in controlling the concentration of pollutants in rainwater. Newman et al. (1974) found that the transport of cadmium and other aerosol contaminants around the southernmost area of Lake Michigan was affected by terrestrial and topographical features.

Although there have been a few studies on the atmospheric aerosol composition and concentrations in industrial and urban air, data on spatial distribution and concentration gradients of cadmium in the air are largely lacking. Long-range aerial transport of cadmium has been estimated indirectly from the studies of soil concentrations surrounding smelters. Miesch and Huffman (1972) observed that cumulative deposits of emissions from local smelters corresponded roughly with the amount accumulated in surrounding soils, less small amounts taken up by vegetation and leaching. Plant uptake of cadmium did not play a major role for cadmium removal from the soil. Miesch and Huffman estimated that about 260 metric tons of cadmium had been accumulated in the soils within a radius of 1 to 16 km from the smelter stack. Cadmium concentrations in uncultivated soil surrounding the East Helena smelter stack decreased from 68 ppm to 4 ppm (0 to 2.5 cm depth) as the distance from the stack increased from 1.8 km to 7.2 km (Table 3.1). However, the estimates appear to be too approximate to identify or to characterize pure atmospheric transport of the element.

TABLE 3.1. CADMIUM CONTENT AND ZN/CD RATIOS IN UNCULTIVATED SOIL SURROUNDING EAST HELENA STACK[a]

Depth of Soil, cm	1.8 km from Stack		3.6 km from Stack		7.2 km from Stack	
	Cd, ppm	Zn/Cd	Cd, ppm	Zn/Cd	Cd, ppm	Zn/Cd
0-2.5	68	16	17	14	4	12
5-10	30	33	7	25	2	15
15-25	3	70	2	42	1	33

[a] Source: Miesch and Huffman, 1972.

Cadmium aerosols in the air are removed by wet deposition through rain and snow, sedimentation (dry deposition), and impaction on obstacles. Andren et al. (1975) reported that the ratio of cadmium to manganese in fly ash was comparable to that of rain, indicating wet deposition is a major mechanism for the removal of cadmium from the air. Cadmium removal by dry deposition at Walker Branch watershed, Oak Ridge, Tennessee, was less than 4.5 percent of the wet deposition.

More complex mechanisms in the atmospheric transport of cadmium were observed by Yost et al. (1974, 1975). In their studies of the City of Chicago and vicinity, they found the flushing of particulates as well as their repeated refloatations, and thus repeated atmospheric transport. The total suspended particulates (TSP) due to refloatation in the Chicago area constituted 20 to 30 percent of the annual mean TSP under normal meteorological conditions. Daily values of TSP could be increased up to 50 percent by refloatation due to winds and traffic on a dry day. Since the refloatation of particulates is not a function of industrial emission sources, studies directed at defining the source of refloated materials are highly desirable.

SOIL TRANSPORT

The normal content of cadmium in uncontaminated soils is probably in the range of less than 1 ppm with about 0.4 ppm on the average (Fleischer et al., 1974). However, the levels of cadmium in soils vary considerably depending upon the extent of pollution and distance from the contaminating sources.

Sargent and Metz (1975) estimated the total amount of land-destined cadmium emission as about 1,500 MT/yr, which is over 82 percent of the total release of cadmium to the environment. Major sources of cadmium in soils are atmospheric fallout and man's input through use of fertilizer and sewage sludge or leaking and dumping of industrial wastes.

The material flow model (Figure 3.2) has been used to simulate the movement of cadmium in the Walker Branch watershed in Tennessee by Raridon et al. (1974). The transported cadmium to the soil environment is absorbed by biota, and adsorbed on soil particles by ion exchange. Most cadmium in the soils is found in the top layer (Lagerwerff et al., 1973; Munshower, 1972; Matti et al., 1975) with downward migration reaching to a depth of at least 30 cm (Kobayashi, 1972). Cadmium leaves the soil environment by direct surface runoff, leaching, and solute interflow by underground pathways or through biochemical activities. Through testing a predictive model of cadmium and lead ion transport in soil systems, Jurinak and Santillan-Medrano (1974) found that cadmium content in soils is regulated mainly by ion exchange or adsorption but not by precipitation except at higher concentrations.

The availability and uptake of cadmium in soils are largely determined by the pH, organic matter, other metals, and the cation exchange capability of the soils. Bolter et al. (1975) reported that organic acids from decaying leaf litter in the soils increase the solubility, and thus, subsequent transport of heavy metals including cadmium. They found higher than background concentrations of cadmium at distances up to 24 km from the smelters.

For soils with an overlying well-decomposed organic litter layer, Wixon and Downey (1977) report consistently low concentrations of cadmium in the soil layers of even smelter-exposed soils. They hypothesize that the litter layer effectively binds the cationic metals, so that even as the organic matter continues to decompose the opportunities for horizontal transport are sufficient to greatly reduce vertical transport to the soil column.

Cadmium appears to be less mobile in the soil than other heavy metals except lead. Huckabee and Blaylock (1974) found that 27 days after tagging with $^{115m}CdCl_2$, 94 to 96 percent of the initial cadmium added was retained in the terrestrial portion of test microcosms, and less than 4 percent was transported to the aquatic portion of the system (Table 3.2). Most of the cadmium remaining in the terrestrial portion (68 to 77 percent) was bound in the soil, with approximately 11 to 15 percent retained in the litter. Matti et al. (1975) showed that about 56 percent of tagged cadmium (^{109}Cd) leached to the soil, and 42 percent adsorbed on the litter with less than 2 percent retained by vegetation.

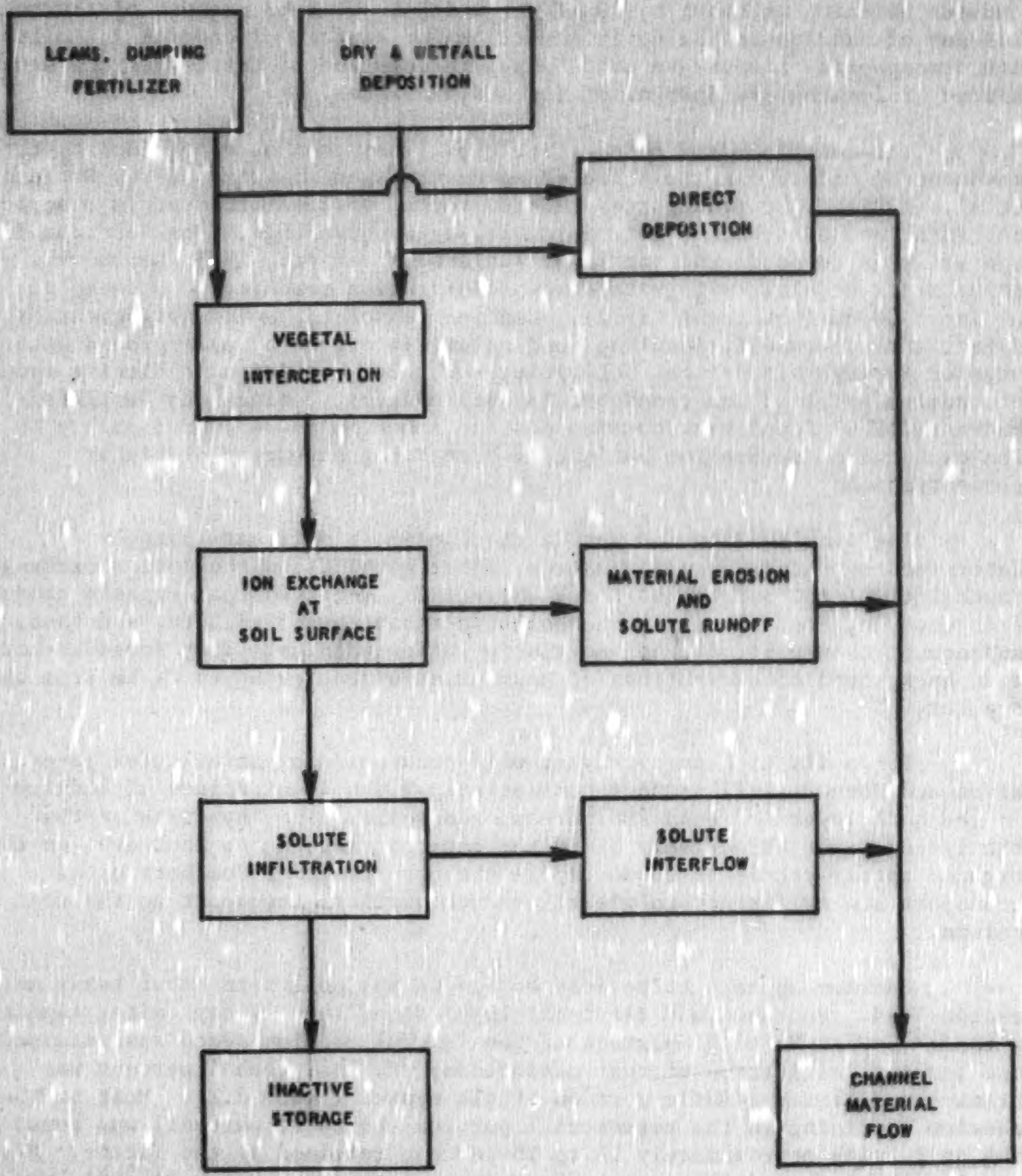

LEAKS, DUMPING FERTILIZER
DRY & WETFALL DEPOSITION
DIRECT DEPOSITION
VEGETAL INTERCEPTION
ION EXCHANGE AT SOIL SURFACE
MATERIAL EROSION AND SOLUTE RUNOFF
SOLUTE INFILTRATION
SOLUTE INTERFLOW
INACTIVE STORAGE
CHANNEL MATERIAL FLOW

Figure 3.2. Flow of cadmium in a land area segment (Raridon et al., 1974).

TABLE 3.2. DISTRIBUTION OF 284 μCi of ^{115m}Cd IN MICROCOSM EXPERIMENTS AT 27 DAYS AFTER TAGGING WITH $^{115m}CdCl_2$[a]

Component	Percent of ^{115m}Cd	
	Microcosm A[b]	Microcosm B[b]
Terrestrial	93.8	95.9
Moss	10.2	8.2
High plants	0.1	0.3
Litter	15.3	10.6
Soil	68.2	76.8
Aquatic	3.4	3.2
Water	0.2	0.2
Sediment	3.1	3.0
Fish	<0.1	<0.05
Snails	<0.1	<0.05
Watercress	<0.09	<0.05
Plastic liner	2.8	1.1

[a] Source: Huckabee and Blaylock, 1974.

[b] These are intact microcosms; A and B are replicates.

In an attempt to quantify the cycling of trace elements in Walker Branch watershed, Andren et al. (1975) determined a complete input-output budget for cadmium. During a 6-month period, the watershed retained about 94-95 percent of the total cadmium input, while less than 6 percent was carried away through the streams. The retention efficiency of cadmium in soils was next highest of the heavy metals, only that of lead being higher. A considerable amount of cadmium appeared to be accumulated in the watershed, and the estimated doubling time was only 9 years for the soil profile of the area.

WATER TRANSPORT

Cadmium occurs as the free ion in surface waters. As it moves through the aqueous environment, it remains as dissolved solids, as particulate matter, or in colloidal form, depending on pH and hardness, and other soluble complexes of water. Some portions of the total cadmium in water are taken up by aquatic life, some discharged, and some are adsorbed or bound to particulate solids and tend to concentrate in the sediment.

Movement and distribution of this element in the aquatic environment are complex and are influenced by the physicochemical and biological conditions within the system. Studies of two streams in Tennessee by Perhac and Tamura (cited in Fulkerson and Goeller, 1973) showed that most of the cadmium in the stream waters was found in the suspended sediment and bottom sediment (3 to 230 ppm), while extremely small amounts (less than 0.003 ppm) were dissolved in water (Table 3.3). Distribution of the tagged cadmium in the aquatic portion of microcosms (Table 3.1) was mainly limited to the sediment, while concentrations in the biota were minimal (Huckabee and Blaylock, 1974). In another study by Fulkerson and Goeller (1973) (Table 3.4), however, the accumulation of the cadmium radioisotope was much greater in living organisms than in the sediment, which consisted mainly of gravel and sand with low organic materials. Initial concentrations (4-hour) in watercress, periphyton, and snails were much higher than in fish, but they were reduced greatly with time, whereas the fish slowly picked up ^{109}Cd, probably through the food chain.

Removal of cadmium from water may be achieved by precipitation as an insoluble salt, or by adsorption on the surface of solids. Gardiner (1974) indicated that adsorption and possible desorption were major factors which influenced the distribution and transport of cadmium in the waters. Hydroxy and chloride complexes contribute to the mobilization of cadmium in waters (Hahne and Kroontje, 1973). Other ligands, such as phosphate, cyanide, carboxylic, hydrocarboxylic, and amino acids, may also contribute to the distribution of cadmium, although these ligands will complex with cadmium only if their concentrations are very high.

Organic materials play an important role in heavy metal mobility by forming organo-metallic complexes (Baker, 1973; Bolter et al., 1975; Schnitzer and Kahn, 1972) which retard precipitation (Rashid and Leonard, 1973). For several southeastern U.S. rivers and estuaries, the organic acids

TABLE 3.3. CADMIUM CONTENT OF WATER, SUSPENDED SEDIMENT, AND BOTTOM SEDIMENT IN TWO TENNESSEE STREAMS[a]

Location	Water, ppm			Suspended Sediment, ppm				Bottom Sediment, ppm		
				Coarse		Fine				
	Cd	Zn	Zn/Cd	Cd	Zn	Cd	Zn	Cd	Zn	Zn/Cd
Joe Mill Creek										
1.6 km (1.0 mi) above outcrop	0.0031	0.010	3.2	15	230	230	50	3	117	39
0.08 km (0.05 mi) below outcrop	0.0028	0.016	5.7	21	2,480	170	1,840	4	280	70
0.96 km (0.6 mi) below outcrop	0.0016	0.025	15.6	24	820	70	1,360	5	300	60
2.4 km (1.5 mi) below outcrop	0.0020	0.033	16.5	15	1,400			3.4	133	39
Holston River										
2.4 km (1.5 mi) above Big Flat Creek	0.0008	0.020	25							
Junction with Big Flat Creek[b]	0.003	0.138	46	32	9,000	460	9,400	66-87	12,000	~150
0.8 km (0.5 mi) below junction)	0.003	0.039	13	61	5,000			31-41	3,500-4,000	~100

[a] Source: Perhac and Tamura (cited in Fulkerson and Goeller, 1973).

[b] Discharge of plant.

TABLE 3.4. CONCENTRATION RATIOS[a] OF ^{109}Cd IN A STREAM ECOSYSTEM[b]

Source	4-Hour	Time, days 1	8	14	28	35	42
Sediments	2.5	2.5	5.5	2	4.5	3	3
Watercress	11.5	8	8	2.5	1.5	1.5	1.5
Periphyton	205	160	30	35	15	10	10
Snails	7.5	4.5	6	6.5	4.5	3.5	2.5
Fish	2	2.5	4	3	5	10.5	15.5

[a] Concentration ratio = activity of Cd/g sample ÷ initial activity of Cd/ml water.

[b] Source: Fulkerson and Goeller, 1973.

were to be significant factors in transportation of cadmium (Windom, 1976). Salt marshes, highly abundant in organic matter, act as a sink for iron, manganese, and particulate cadmium.

Cadmium concentrations and their transport by U.S. rivers have not been investigated utilizing reliable analytical techniques. However, older studies suggest that highest cadmium flows were found in the mineralized areas of the Mississippi-Missouri rivers (Durum et al., 1971). Cadmium flow was also reportedly high in the Illinois River. These data further suggest that mining drainage and industrial effluent were the major sources of cadmium contamination in rivers. Sargent and Metz (1975) indicate that the waterborne cadmium effluent from industry is approaching comparatively negligible quantities due to improved technologies for wastewater treatment and cadmium removal.

Table 3.5 summarizes data on the cycling budgets for cadmium in several watersheds and salt marshes. Approximately 95 percent of the introduced cadmium in the Walker Branch watershed in Tennessee was retained, while only 17 percent of the total cadmium input (in rain) remained in the Atlantic salt marshes. More variations in cadmium transport, ranging from 9 to 89 percent, were observed in the 8 small watersheds in Delaware (Biggs et al., 1973). This may be due to the amount of stream discharge and available organic acids in the ecosystems. Proportions of cadmium transported as dissolved and particulate species in the Walker Branch stream were 99.4 and 0.6 percent, respectively, and for the southeastern Atlantic salt marshes, were 78.8 and 21.2 percent.

TABLE 3.5. CADMIUM CYCLING BUDGETS IN SEVERAL WATERSHEDS AND SALT MARSHES

Location	Total Cadmium Input	Total Stream Output Net Flux	Input, %	Reference	Remarks
Walker Branch Watershed Oak Ridge, Tennessee	63.9 g/ha/6 months	3/5 g/ha/6 months	5.5 (Range: 5-6)	Andren et al, 1975	97.5 ha catchment
Delaware Watersheds	1,387.1 kg/yr	285.1 kg yr	20.6 (Range: 9-89)	Biggs, et al., 1973	8 small watersheds
Southeast Atlantic Salt Marshes--South Carolina, Georgia, Florida	52×10^3 kg/yr	43×10^3 kg yr	82.7	Windom, 1976	Coastal rivers and littoral-salt marsh estuaries

SEDIMENT TRANSPORT

The distribution patterns in the sediments appeared to be mainly a function of water current, basin depth and slope, winds and shoreline patterns (Browne, 1975; Klein and Russell, 1973; Peyton and McIntosh, 1974). In the vicinity of Erie, Pennsylvania, Browne (1975) found that the site with the highest concentration of cadmium in the sediment was not associated with a tributary, nor were the water concentrations significantly higher than those at other stations. This may indicate that the area nearest the emission source may not necessarily be the most severely affected area, perhaps due to currents and wind activities. Cadmium in water may not disperse evenly or settle out rapidly but be carried by currents or wave action to other areas.

Generally, areas undergoing more mixing and having less vegetation accumulate less heavy metals in the sediments (Browne, 1975). Accumulations by vegetation and bacteria and subsequent decompositions affect the retention of the metals in the sediments. The presence of other heavy metals, such as lead (0.1 to 0.5 ppm) may inhibit bacterial decomposition and thus alter cadmium content. Moyer and Budinger (1974) indicated that sulfur dioxide might play an important role in precipitation of cadmium as greenockite (CdS) from dissolved cadmium salts. This mechanism was suggested for higher cadmium levels in tidal shoreline sediments in San Francisco Bay. Oxidate sediments such as manganese nodules also adsorb significant amounts of cadmium as do phosphorite deposits of organic origin. Selenium and cadmium will precipitate as cadmoselite (CdSe) into the sediments.

Tidal effects on cadmium concentrations were observed in Foundry Cove on the Hudson River, New York (Kneip et al., 1975). With rising ebb tide, alkalinity and dissolved oxygen increased which resulted in increased insoluble cadmium concentrations. Bondietti et al. (1974) found that the carbonate-rich sediments of Foundry Cove stabilized the cadmium, thus limiting its availability for chemical and biological reactions. The sediments of Long Island Sound appear to have become progressively more enriched in cadmium over the past 100 years (Turekian, 1974). The sediments below about 2 cm become anoxic, allowing sulfate-reducing bacteria to produce H_2S, which reduces solubility and, therefore, mobility of most heavy metals (Turekian, 1974). Metals that do escape are sequestered by the precipitation of iron and manganese oxide formation at the sediment/water interface; therefore, there is little chance of metal escaping in the estuary except for extreme perturbations. Disturbances by dredging, turbulence, and biological activities of living organisms may induce redistribution of the sedimented cadmium. The relative insolubility of cadmium and its tendency to adsorb and complex with other particulate matter appear to destine it to the sediments of the estuaries and oceans.

FOOD CHAIN TRANSPORT

Man depends on the following major trophic compartments for food:

- Land plants
- Land animals and animal products
- Freshwater fish
- Marine fish and free-moving crustaceans
- Shellfish.

Using various references cited elsewhere in this report, potential dietary pathways by which man can be exposed to cadmium were constructed (Table 3.6). Mean concentrations of cadmium vary among the five major food groups. Concentrations (ppm) in milk averaged <0.01; marine fish, freshwater pond fish, and land plants <0.3; mammals, birds, and shellfish, about 0.7. Finally, freshwater stream fish exhibited the highest average, 1.87.

TABLE 3.6. TRENDS OF ARITHMETIC AVERAGE CONCENTRATIONS (PPM) OF CADMIUM IN DIETARY FOOD GROUPS IN TWO MAJOR FOOD PATHWAYS TO MAN[a]

Land-Based Food Chains to Man		Water-Based Food Chains to Man		
Plants	Animal	Freshwater Fish	Marine Fish/ Crustaceans	Shellfish
0.261	0.756 (mammals) 0.496 (birds) 0.008 (milk)	0.112 (pond) 1.87 (stream)	0.102	0.889

[a]Various references—cited elsewhere in this report.

Marine and pond fish move freely in essentially standing-water ecosystems where cadmium concentrations are relatively low compared to soil and sediments. Fish in moving-water systems are exposed to the constant flow of cadmium leached from the land, are near the stream/sediment interface, and eat invertebrates which may contain up to 60 ppm of cadmium (see Section 2). Sessile marine shellfish live at a water/sediment interface where filter and sediment feeding exposes them to greater quantities of cadmium than does the water column. Thus, the foods in the water-based food chain with lowest concentrations are marine and pond fish. Higher exposures may be involved by eating freshwater stream fish and shellfish.

In the land-based food chain to man, animals showed higher average concentrations than did plants, although milk was very low. The matching of plant species with those herbivores which specialize on those species and man within food chains will be necessary to develop a defendable conclusion, but it appears that animal parts would expose man to more cadmium than would plants. Foods produced by terrestrial ecosystems show intermediate concentrations of cadmium between (1) marine and pond fish and (2) stream fish and shellfish.

The above observations should be tempered with the fact that uptake of cadmium by plants and animals is insignificant compared to cadmium loads in the soil, although some living organisms are known to accumulate cadmium greater than their background levels by orders of magnitude. Munshower (1972) reported that cadmium loads in plants and herbivore animals were less than 0.1 percent of the soil cadmium load in an area about 15 miles from the smelter near Deer Lodge Valley, Montana.

4. CADMIUM IN FOODS

SOURCES OF FOOD CONTAMINATION

Incorporation of cadmium into foods can take place through a variety of mechanisms. For grains and processed foods, several of these contamination mechanisms seem to operate simultaneously (Fishbein, 1974). Listed in order of importance, they are:

(1) Uptake from soils by roots of plant foods. This may occur:

  a. Naturally as a normal constituent of soils of marine origin

  b. As an impurity (cadmium oxide) in phosphate-treated soils, especially "superphosphate"

  c. In soils fertilized by sludge containing cadmium

  d. As an impurity of zinc in certain zinc-containing fungicides and herbicides

  e. By deposition on plants and soil by cadmium-containing pesticides

  f. By soil contamination from runoff of mine tailings or from electroplating washing process.

(2) Meat animals may accumulate cadmium from

  a. Feeding on crops which have absorbed cadmium. The organs of such animals may have very high cadmium concentrations.

  b. From cadmium-containing helminth killers, used especially in swine.

(3) Molluscs and crustaceans normally concentrate cadmium from ambient waters, as do most other aquatic organisms.

(4) Contamination of foods from use of zinc-galvanized containers, cans, implements or cooking vessels, or utensils used in food preparation, particularly grinders, pressing machines, or galvanized netting used to dry fish and gelatin.

(5) Contamination from absorption of cadmium contained in wrapping and packaging materials such as paper, plastic bags, and tin cans.

(6) Use of cadmium-contaminated water in cooking or processing operations.

For the general population, oral ingestion of foods may represent the most important source of cadmium intake. Airborne sources constitute a significant portion of cadmium intake only for those occupationally exposed, particularly to cadmium oxide fumes, or those residing in areas heavily polluted by cadmium-emitting industries (Friberg et al., 1973).

Continued, low-dose exposure to cadmium in foods is of great concern because the long biological half-life of cadmium, 17 to 33 years, permits substantial accumulation in the body (Deane et al., 1976).

CIGARETTES

Lewis et al. (1972) found that cigarette smoking provides a surprisingly great contribution to cadmium intake and subsequent body burden. After examining cadmium levels in liver, lungs, and kidney from autopsy tissues, they estimated body retention levels of 1 μg/day or less from nonsmokers compared to 2.5 μg/day for smokers. Indicated in Table 4.1 is the magnitude of the contribution to daily intake from cigarettes. The respiratory intake from 2 packs per day ranges between 4 to 6 μg, supplying over 30 percent of daily cadmium retention for the pack-a-day smoker and 56.6 percent of retention for the 3-packs-a-day smoker (Deane et al., 1976). The amount of cadmium inhaled from 2 packs of cigarettes per day equals 10 to 20 times the estimated intake from air in lower Manhattan (Fleischer et al., 1974). Yet despite the possible exceptions mentioned--occupational exposure, residents of heavily polluted areas, or heavy cigarette smokers--Table 4.1 illustrates that diet is generally by far the greatest source of cadmium.

FOODS

Unlike many other metals which are restricted to a narrow range of foods, cadmium has an extremely generalized distribution. Of the 33 pesticide residues detected in food composites by the National Pesticide Monitoring Program in FY 1971, cadmium heads the list as the most frequently found residue with two-thirds of 360 composites reporting positive findings with the range of values for the positive composites being 0.01 to 0.20 ppm (Manske and Corneliussen, 1974). Cadmium is found in measurable quantities in all food groups, but it is uncertain whether the cadmium content of most food is ubiquitous or "natural", or whether cadmium has been introduced into foods and beverages as an industrial contaminant.

TABLE 4.1. MEDIA CONTRIBUTIONS TO NORMAL RETENTION OF CADMIUM[a]

Medium	Exposure Level	Daily Retention, μg
Ambient air	0.03 μg/m^3	0.15
Water	1 ppb	0.09
Cigarettes Packs/day	μg/day[b]	
1/2	1.1	0.70[c]
1	2.2	1.41[c]
2	4.4	2.82[c]
3	6.6	4.22[c]
Food	50 μg/day	3.0

[a] Source: Deane et al., 1976.

[b] Based on 0.11 μg per cigarette.

[c] Assumes a 6.4 percent retention rate.

Friberg et al. (1973) have collected and reviewed extensive data on cadmium in foods. There seems to be general agreement that foods average about 0.05 ppm cadmium (wet weight); however, there is substantial variation depending on the source (Fleischer et al., 1974).

Estimates derived from analysis of institutional diets (Murthy et al al., 1971), school lunch studies (Murphy et al., 1971), and the continuing Market Basket Program of the National Pesticides Monitoring Program (Friberg et al., 1973; Manske and Corneliussen, 1974; Mahaffey et al., 1975) represent further attempts to quantify cadmium intake in the context of a normal diet. Table 4.2 presents estimates of daily cadmium obtained from six dietary surveys in the U.S. Most studies coincide reasonably well with the 30 to 70 μg/day range which has been proposed by Friberg et al. (1973) as the typical dietary cadmium intake for Americans.

TABLE 4.2. ESTIMATED DAILY CADMIUM INTAKE FROM FOODS IN VARIOUS LOCATIONS IN THE UNITED STATES[a]

Date of Sample Collection	Concentration, μg/day		Reference	Remarks
	Mean	Range		
1966	39	<141	Murphy et al., 1971	School lunch survey
1967	92	32-158	Murthy et al., 1971	Institutional total diet study
1969		170[b]	Friberg, 1971	
1973	51.2		Mahaffey et al., 1975	FDA total diet study

[a] Source: Mahaffey et al., 1975.

[b] Assayed without preliminary extraction.

Studies of seasonal and regional variations have failed to reveal any meaningful trends or geographic patterns (Murthy et al., 1971; Murphy et al., 1971). This is illustrated in Figure 4.1 which shows the distribution of cadmium levels in institutional diets in the United States.

Table 4.3 contains Friberg's interpretation (1974) of data taken from Corneliussen (1970) and Duggan and Corneliussen (1972). Their work covers studies made on samples collected from 30 markets in 24 cities in the United States.

The FDA National Pesticides Monitoring Program's Market Basket Program utilizes samples collected from 30 markets in 27 U.S. cities. Foods are purchased according to a specified list of 117 items. Content and portions are prepared to simulate the diet of a 16 to 19-year-old male, statistically the largest eater. Market Basket Program data show that on a national basis cadmium was: (1) found in composites from all food categories and (2) present in greater than 10 percent of composites in all food groups (Carroll et al., 1975). Composites of potatoes, root vegetables, garden fruits, and oils, fats, and shortenings yielded positive findings in over 90 percent of composites.

Fish and shellfish typically have elevated cadmium concentrations, but as a rule are not consumed in large quantities by most Americans. As shown in Table 4.4, lower levels of cadmium in potatoes, fruits, and grains and cereals may warrant greater concern, because these foods are consumed in

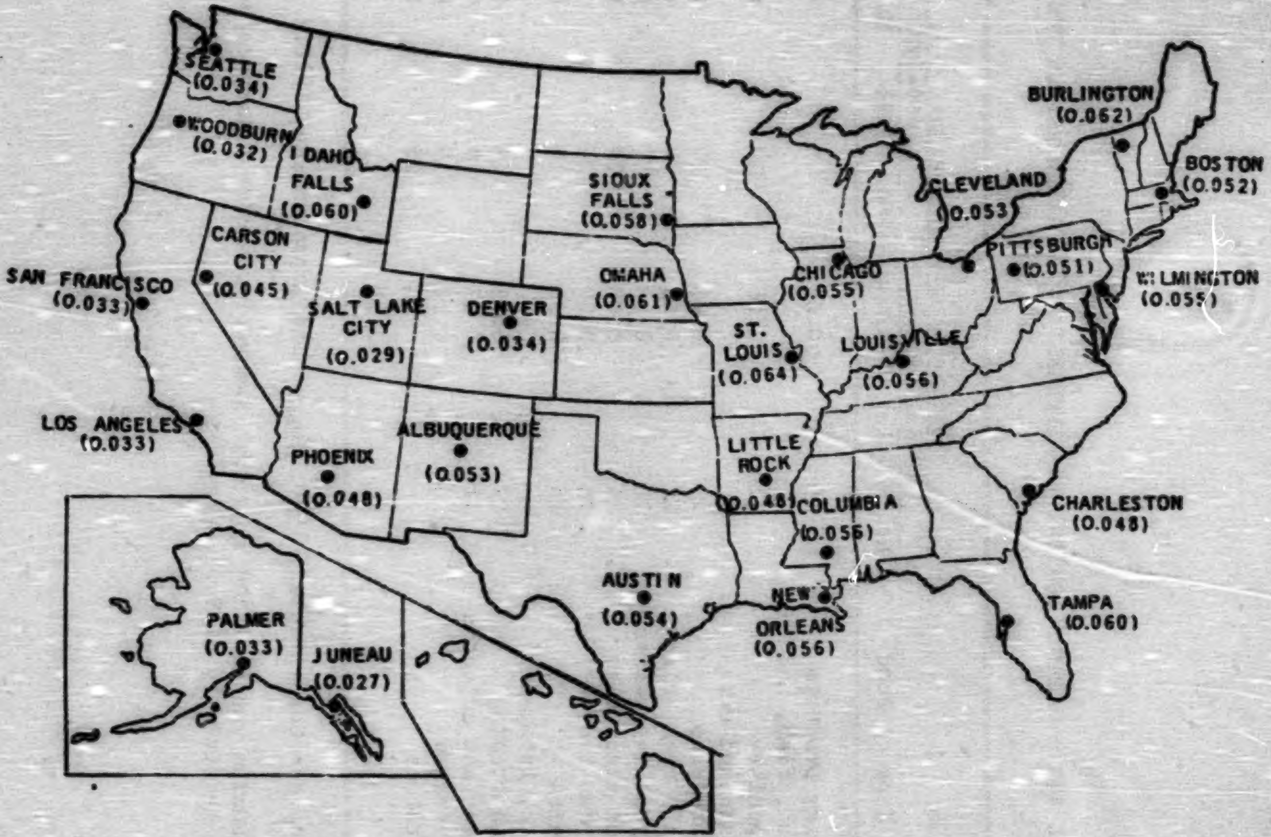

SEATTLE (0.034)
WOODBURN (0.032)
IDAHO FALLS (0.060)
CARSON CITY (0.045)
SAN FRANCISCO (0.033)
SALT LAKE CITY (0.029)
DENVER (0.034)
LOS ANGELES (0.033)
PHOENIX (0.048)
ALBUQUERQUE (0.053)
SIOUX FALLS (0.058)
OMAHA (0.061)
ST. LOUIS (0.064)
LITTLE ROCK (0.048)
AUSTIN (0.054)
CHICAGO (0.055)
LOUISVILLE (0.056)
COLUMBIA (0.056)
NEW ORLEANS (0.056)
CLEVELAND (0.053)
PITTSBURGH (0.051)
BURLINGTON (0.062)
BOSTON (0.052)
WILMINGTON (0.055)
CHARLESTON (0.048)
TAMPA (0.060)
PALMER (0.033)
JUNEAU (0.027)

Figure 4.1. Average values (in ppm) of cadmium content in institutional total diets, 1967 (Murthy et al., 1971).

TABLE 4.3. CADMIUM CONTENT IN DIFFERENT FOOD CATEGORIES IN THE U.S.A.[a,b]

Type of Food	Cadmium, µg/g wet weight			
	1968-1969		1969-1970	
	No. >0.01	Maximum	No. >0.01	Maximum
Dairy products	10	0.09	9	0.01
Meat, fish, and poultry	21	0.06	22	0.03
Grain and cereal products	27	0.08	27	0.06
Leafy vegetables	27	0.08	28	0.14
Legume vegetables	16	0.03	10	0.04
Root vegetables	24	0.08	27	0.08
Garden fruits	25	0.07	27	0.07
Fruits	15	0.38	10	0.07
Oils, fats, and shortening	27	0.13	28	0.04
Sugar and adjuncts	18	0.07	9	0.04
Beverages	8	0.04	9	0.04
Potatoes	-	-	29	0.08

[a] Source: Corneliussen, 1970; Duggan and Corneliussen, 1972.

[b] Cadmium was analyzed by atomic absorption and/or polarography at a sensitivity of 9.01 µg/g.

vastly greater quantities than fish and, consequently, contribute a large proportion of dietary cadmium. Two food classes, (1) meat, fish, and poultry, and (2) dairy products, have positive findings for cadmium less frequently than would be expected if food chain accumulation of cadmium were significant (Table 4.5). Mean concentrations in these food groups ranked eighth and twelfth out of 12, respectively (Mahaffey et al., 1975). Studies of the Market Basket type, which analyze foods in composite categories rather than performing cadmium determinations on individual foods, run the risk of concealing foods which may contain unusually high cadmium concentrations, by combining them into composites with other foods typically having much lower cadmium content. Undoubtedly, this factor applies when meats and poultry are composited with fish.

In 1973 the FDA initiated a new program called the Heavy Metals in Foods survey designed to measure the content of lead, cadmium, and zinc in individual foods rather than composites (U.S. Department of Health, Education, and Welfare, 1975). Criteria for selection of foods to survey were (1) relative importance in the diet, both adult and infant, (2) past indication of particularly high levels in the selected foods, and (3) balanced coverage of raw and processed foods. The following is a summary of the mean levels of cadmium found in the 41 foods surveyed. Foods are grouped as adult noncanned foods, adult canned foods, and baby foods to provide an overview as to whether canning might be a source of increased cadmium in foods:

Category	Cadmium, ppm
All adult foods (32)	0.047
Canned adult foods (13)	0.029
Noncanned adult foods (19)	0.060
Baby foods (9)	0.024

It appears that cadmium levels are not affected by canning processes. Comparing fruits and vegetables in jars and cans with raw vegetables shows canned foods do not contain increased cadmium levels. Cadmium levels in selected adult foods are presented in Table 4.5. Cadmium concentrations in meats are generally higher and more than in most other foods. Concentrations in grains and cereal items are also higher than in most other foods. Among adult foods, raw liver had the highest mean cadmium level, 0.183 ppm. Sugar, hamburger, and eggs followed with mean levels of 0.100, 0.075, and 0.067 ppm, respectively. Milk and canned peas were lowest with means of 0.008 ppm for both. Overall, 99 percent of adult samples had 0.68 ppm or lower and 35.3 percent had no detectable cadmium.

Results for the baby foods surveyed are presented in Table 4.6. Spinach had the highest mean level, 0.057 ppm. Orange juice, mixed vegetables, and vegetables and beef were next in order, having means of 0.040, 0.034, and 0.026 ppm, respectively. Peaches, 0.003 ppm, and applesauce, 0.007 ppm, had the lowest baby food means.

TABLE 4.4. FOOD GROUPS BY MEAN CADMIUM CONTENT AND THEIR CONTRIBUTION TO DAILY CADMIUM INTAKE[a]

Food Group	Concentration, ppm Mean	Intake, µg/day	Percent of Total Daily Diet	Contribution to Daily Cadmium Intake, %
Leafy vegetables	0.051	3.18	2.0	6.2
Potatoes	0.046	9.11	7.0	17.8
Fruits	0.042	9.38	7.4	18.3
Grains and cereals	0.028	11.66	12.6	22.8
Oils, fats, and shortening	0.027	1.36	1.8	2.7
Root vegetables	0.021	0.76	1.2	1.5
Garden fruits	0.019	1.71	3.0	3.4
Meats, fish, and poultry	0.0093	2.49	9.9	4.9
Sugars and adjuncts	0.0083	0.68	2.8	1.3
Legume vegetables	0.006	0.42	2.5	0.8
Beverages	0.0057	6.49	23.9[b]	12.7
Dairy	0.005	3.94	25.9	7.7

[a] Source: Mahaffey et al., 1975.

[b] Includes water.

TABLE 4.5. CADMIUM CONTENT OF SELECTED ADULT FOODS[a]

Commodity	No. of Samples	Average, ppm	Standard Deviation, ppm
Carrots, roots fresh	69	0.051	0.077
Lettuce, raw crisp head	69	0.062	0.124
Potatoes, raw white	71	0.057	0.139
Butter	71	0.032	0.071
Margarine	71	0.027	0.048
Eggs, whole fresh	71	0.067	0.072
Chicken fryer, raw whole or whole cut up	71	0.039	0.088
Bacon, cured raw, sliced	71	0.040	0.160
Frankfurters	69	0.042	0.111
Liver, raw beef	71	0.183	0.228
Hamburger, raw ground beef	71	0.075	0.122
Roast, chuck beef	71	0.035	0.034
Wheat flour, white	71	0.064	0.150
Sugar refined, beet or cane	71	0.100	0.709
Bread, white	70	0.036	0.063
Orange juice, canned frozen concentrate	71	0.029	0.095
Green beans, canned	71	0.018	0.072
Beans, canned with pork and tomato sauce	71	0.009	0.000
Peas, canned	71	0.042	0.113
Tomatoes, canned	71	0.042	0.113
Diluted fruit drinks, canned	71	0.017	0.052
Peaches, canned	71	0.036	0.061
Pineapple, canned	71	0.059	0.153
Applesauce, canned	71	0.020	0.027

[a] Source: U.S. Department of Health, Education, and Welfare, 1975.

TABLE 4.6. CADMIUM CONTENT OF SELECTED BABY FOODS[a]

Commodity	No. of Samples	Average, ppm	Standard Deviation, ppm	Range, ppm	
				Low	High
Vegetables and beef	71	0.026	0.035	0	0.24
Mixed vegetables	71	0.034	0.052	0	0.401
Spinach	69	0.057	0.054	0	0.43
Orange juice	71	0.040	0.084	0	0.43
Apple juice	71	0.023	0.035	0	0.264
Applesauce	71	0.007	0.023	0	0.18
Pears	71	0.013	0.053	0	0.520
Peaches	71	0.003	0.005	0	0.04
Apricots	71	0.011	0.037	0	0.32

[a] Source: U.S. Department of Health, Education, and Welfare, 1975.

Table 4.7 shows yearly values in the cadmium content of U.S. foods, as obtained from the FDA's total diet surveys. No trends of increasing or decreasing cadmium levels were noted from 1968 to 1974.

Foods processed by grinding, milling, powdering, drying, or pressing often appear to contain cadmium in larger amounts than in the original ingredients. "Instant" products, for example, coffees and teas, as well as some condiments and spices appear to contain abnormally high levels of cadmium. The precise mechanism of the possible transfer of cadmium from processing equipment to these foods has not been investigated. In Table 4.8 Schroeder (1974) presents some speculations. In an analytical study of paper products commonly used for packaging foods, Lagerwerff and Specht (1971) found 0.22 ppm of cadmium in thin cardboard and 0.30 ppm in gloss paper, presumably of the type used inside food boxes. Again, the mechanism for the possible transfer of cadmium in packaging materials to foods remains to be investigated.

TABLE 4.7. CADMIUM CONTENT OF FOODS BY YEAR AND DAILY INTAKE[a] (micrograms/day)

1968	1969	1970	1971	1972	1973	1974[b]
26	61	38	29	37	51	34

[a] Source: Mahaffey et al., 1975.

[b] Estimated level.

TABLE 4.8. POTENTIAL EXPOSURES OF HUMAN BEINGS TO CADMIUM FROM FOOD SOURCES[a]

Source	Remarks
Galvanized iron pipes	Soft and acid waters dissolve from zinc coating.
Galvanized iron roofs	Dissolved by rainwater.
Galvanized iron cisterns and tanks	Dissolved by soft water.
Cola drinks	From processing, usually 10 μg/quart or less.
Instant coffees	From processing.
Oysters	Up to 7 ppm, with much zinc.
Some canned and dried fish	From canning, dying, or smoking. Galvanized wire netting?
Pigment in candy	"Luv beads" make children ill.
From plastic wrappings	Absorbed by food.
Plated ice trays	Dissolved by acid sherbets.
Plated roasting pans	Dissolved by roasting fats.
Pigmented pottery	Dissolved by acid foods and juices.
Silver polish	Residue on eating utensils.
Pork kidneys	Cadmium used as a vermifuge.
Butter	Probably from galvanized milk cans.
Olive oil	From cans and presses.
Gelatin, dried fish	From galvanized netting for drying.
Many processed meats	From contact in processing machines.
Tin and aluminum cans	Tin cans made of old cars, aluminum from old aircraft.

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[a] Reprinted from The Poisons Around Us by H. A. Schroeder, by permission of Indiana University Press. Year of publication 1974.

5. CADMIUM IN MAN

Cadmium is a highly toxic element with no known useful biological function except as might be indicated by Schwartz' studies (1977). The need for precautions in industrial operations in which workers are exposed to dusts and vapors of the elements has long been known, and in recent years concern has been expressed over the possible effects on human health of chronic exposure to low concentrations of cadmium. This concern has been triggered by (1) the steadily increasing industrial consumption and consequent rise of cadmium levels in the environment and (2) the outbreak in Japan of Itai-Itai disease in the late 1940's and early 1950's.

DISTRIBUTION OF CADMIUM

The average human intake of cadmium is about 50 to 75 μg/day, chiefly from food. Intestinal absorption, which is governed by nutritional factors, is about 6 to 10 percent. Absorption through the lungs, which plays the major role in occupational exposures, ranges from 10 to 40 percent. The significance of inhalation exposure depends upon the concentration, particle size, solubility of the particulate matter, and the physiologic parameters such as the rate and depth of the respiration. Threshold limit values adopted by the American Conference of Governmental Industrial Hygienists for cadmium dusts, fumes, and salts (as cadmium) are 0.05 mg/m^3. Cigarette smoke is also a source of cadmium absorption via the pulmonary route. Cadmium accumulates in the kidney cortex, where it can cause renal tubular dysfunction at levels of approximately 200 ppm in outer cortex. Autopsy studies show current levels of 15 to 50 ppm in kidneys of people over 50 who were not occupationally exposed. The higher levels generally were found in individuals who had been smokers. Cadmium accumulation in the placenta during pregnancy has been reported as not more than 5 ppm; in the neonate, 1 ppm. However, with years of nonindustrial exposure, the average body burden at age 50 has been estimated in the U.S. at about 30 mg. This is reflected by increased concentrations of cadmium not only in the kidney and liver but also in the pancreas and blood vessels. About 5 percent of ingested cadmium is retained in the body and its biological half-life in humans is estimated to be about 15 to 50 years. Absorbed cadmium is transported in the red blood cells. The normal cadmium blood level is below 1 μg/100 ml; but in exposed workers, the range may be from 1 to 10 μg/100 ml. Normal urinary levels of cadmium in the U.S. are in the range of 0.5 to 10 ppm. The urine is the primary route of excretion of absorbed cadmium. Secondary routes of excretion occur in the feces and in hair.

BODY BURDEN

Table 5.1 summarizes cadmium levels in various tissues of exposed and nonexposed persons. "Nonexposed" refers to persons living under normal environmental levels of cadmium in air, water, and food. "Exposed" refers to persons having occupational contact with cadmium or to residents of areas with elevated ambient levels of cadmium, or in the case of Lewis et al. (1972), the exposed and nonexposed categories differentiate between persons who are exposed to cadmium through cigarette smoking and nonsmoking individuals. The high levels in the kidney and liver are believed to reflect the storage of cadmium in metallothionein (Hammons and Huff, 1975). However, autopsy studies have revealed that smaller, yet significant, amounts of cadmium may accumulate in the lungs, pancreas, adrenal glands, thyroid, spleen, salivary glands, and testes.

Hammer et al. (1973) state that body burdens are best estimated from the total cadmium content of the kidney and the liver. Noncigarette smoking males, aged 40 to 70, have about 5.2 mg of cadmium in their kidneys and about 3.7 mg of cadmium in their liver or a combined total of 8.9 mg. Comparable figures for males smoking one-half pack or more daily would be 11.4 mg in the kidney and 7.5 mg in the liver for a combined total of 18.9 mg of cadmium in these two organs. Since the amount in the kidneys and liver represents approximately 50 percent of the adult body burden, this is estimated to be about 17.8 mg of cadmium for male nonsmokers and about 37.8 mg of cadmium in smokers.

As presented in Table 5.2, data reported by Lewis et al. (1972) show that adult American male nonsmokers with mean age of 60 have, on the average, a total body burden of about 13 mg of cadmium. In contrast, the adult cigarette smokers have a total body burden of 30 to 40 mg. The difference between the two groups suggests that more than one-half of the cadmium found in the smoking group comes from cigarette smoking. Cigar and pipe smokers yielded average cadmium values. Ex-smokers had mean total organ and composite values similar to those of light cigarette smokers. The multiple regression analysis of composite cadmium content of each organ for each subject implicates cigarettes as a major source of the total body burden of cadmium. Lewis et al. (1972) found that when control is made for smoking habits, subjects with chronic bronchitis, emphysema, cancer of the bronchus or lungs, and arterial hypertension do not have more cadmium in their tissues than those without. Table 5.3 illustrates the contribution of the various media to cadmium retention and subsequent body burden (Environmental Health Resources Center, 1973). Intake levels of less than the given amounts would result in body burden of less than 30 mg/45 years. Friberg et al. (1974) suggest that currently the body burden of adults in the United States is in the 15 to 20 mg range.

Placental Transfer

The effectiveness of the placental barrier in protecting the fetus from cadmium varies with dose and with time during pregnancy. Normally in

TABLE 5.1. SUMMARY DATA ON CADMIUM LEVELS IN VARIOUS TISSUES OF EXPOSED AND NONEXPOSED PERSONS

Tissue	Age	Sex	Concentration, ppm Nonexposed	Concentration, ppm Exposed	Reference	Remarks
Renal Cortex	50-75		25-50[a]	20-500[b]	Friberg et al., 1974	About 2/3 of workers were above 100 ppm average.
Blood			0.01 10[c]	0.01-0.1 0.41[d]	"	Levels below 0.1 most typical.
Urine			1-2[e]	Up to 100 μg/day	"	
Feces			31[e]	NA[f]	"	
Hair		Female	1.77		Schroeder and Nason, 1969	
	10	Male	1.3	3.5	Hammer et al, 1971	"Nonexposed" refers to residents of lowest two population levels. "Exposed" were residents of heavy pollution area rather than industrial exposure.
Kidney			14.8	31.1	Lewis et al., 1972	Exposure to cadmium from cigarette smoking--not industrial exposure.
Liver			1.38	2.05		
Lung			0.33	0.56		

[a] Wet weight.
[b] Upper limit approximate.
[c] Nanograms per gram.
[d] Mean value.
[e] Micrograms per day.
[f] NA = Not available.

TABLE 5.2. CADMIUM CONCENTRATION IN WET TISSUE, SMOKERS AND NONSMOKERS[a]

				Concentration, ppm, ash weight[b]	
Date of Data Collection	Source	No. of Samples	Organ	Mean	Standard Error of the Mean, ppm
Nonsmokers					
ca. 1971	Male	23	Kidney	13.2	2.33
		23	Liver	1.06	0.11
		21	Lung	0.30	0.05
	Female	11	Kidney	18.0	2.83
		11	Liver	2.06	0.29
		9	Lung	0.41	0.10
	Total	34	Kidney	14.8	1.86
		34	Liver	1.38	0.24
		30	Lung	0.33	0.04
Cigarette Smokers					
ca. 1971	Light, <1 pack/day	11	Kidney	24.3	3.00
		11	Liver	1.79	0.32
		11	Lung	0.51	0.11
	Moderate, >1 pack/day but <2 packs/day	57	Kidney	32.5	2.49
		57	Liver	2.02	0.17
		56	Lung	0.59	0.59
	Heavy, >2 packs day	37	Kidney	30.9	2.28
		38	Liver	2.16	0.22
	Total, cigarette smokers	105	Kidney	31.1	1.63
		106	Liver	2.05	2.05
		103	Lung	0.56	0.03
Ex-Cigarette Smokers					
		21	Kidney	21.6	2.49
		21	Liver	1.69	0.18
		19	Lung	0.70	0.13

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[a] Source: Lewis et al., 1972.

[b] Data were collected at Boston, Massachusetts, Veterans Administration Hospital and Providence, Rhode Island, Roger Williams Hospital.

TABLE 5.3. CADMIUM BODY BURDEN MEDIA RETENTION[a]

Cadmium Source	Concentration		
	µg/day	mg/year	mg/45 years
Food and water ingestion: 50 µg/day x 0.025	1.25	0.46	20.1
Cigarettes: 0.067 µg/cigarette x 10 cigarettes/day	0.67	0.25	4.9[b]
Air: 20 m^3/day x 0.30 x 0.05 µg/m^3	0.30	0.11	5.0
			30.0

[a] Source: Environmental Health Resources Center, 1973.

[b] Estimate based on 20-year period.

humans the placenta is an effective barrier. The total body content of cadmium in newborn fetuses from West Germany was less than 1 µg (Hammons and Huff, 1975). In areas where the normal daily uptake of cadmium is higher than that in West Germany, Japan, for example, higher fetal cadmium levels may occur (Chaube et al., 1973).

Placental and Fetal Levels

Baglan et al. (1974), in a study of human placentas as possible indicators of environmental exposure, measured the levels of eight trace metals, including cadmium, in placentas, maternal blood, and fetal blood. In general, the placental levels of metals exceed both maternal and fetal blood levels, and the maternal blood levels exceed the fetal blood levels. Data for cadmium are shown in Table 5.4.

Dawson et al. (1968) investigated seasonal variations in nine cations including cadmium in normal term placentas. Results from 554 placentas indicated a seasonal variation in mean monthly levels of sodium, potassium, magnesium, and lead. Race, maternal age, and pregnancy had no observable effect.

In areas where there is an abnormally high intake of cadmium, elevated fetal levels of cadmium may occur (Chaube et al., 1973. These investigators determined zinc and cadmium concentrations in 36 first-trimester intact human embryos and in liver, brain, and kidney of 14 second- and 1 third-trimester fetuses. Zinc increased sevenfold between the 31st and 35th day of gestation. Cadmium was present in 57 percent of specimens in concentrations from 0.032 ppm to 0.07 ppm of wet tissue. In second

TABLE 5.4. MEAN CADMIUM LEVELS IN HUMAN PLACENTAS, MATERNAL BLOOD, AND FETAL BLOOD[a]

Number of Samples	Organ Site	Concentration, ppm[b] Mean	Remarks
135	Placenta	0.102 ± 0.077	Placentas obtained from four large Nashville hospitals.
83	Maternal blood	0.093 ± 0.115	
123	Fetal blood	0.076 ± 0.109	

[a] Source: Baglan et al., 1974.

[b] Samples were collected from September, 1971, to November, 1972, in Nashville, Tennessee.

trimester specimens, mean zinc concentration in brain was 5.6 ppm, in kidney 15.7 ppm, and in liver 167.7 ppm. Cadmium was present in 80 percent of livers (mean, 0.113 ppm), 28 percent of kidneys (mean, 0.05 ppm), and 17 percent of brain specimens (mean, 0.140 ppm). Although mothers of these fetuses did not live in areas of Japan where endemic cadmium poisoning exists, the higher cadmium content of the average Japanese diet may be reflected in the cadmium concentrations of these specimens.

Cadmium Levels and Distribution in Blood

Studies of cadmium levels in whole blood in normal, nonexposed human populations generally reveal whole blood cadmium levels of less than 1 μg/100 ml; but in exposed workers the range may be from 1 to 10 μg/100 ml. Friberg et al. (1971) caution, however, that the analytical methods have not been sufficiently perfected to enable accurate determination of cadmium in blood because the usual quantities of cadmium observed in blood are so small. Within the blood, more cadmium is in the plasma than in the cells in those persons without known exposure to cadmium (Friberg et al., 1971). A ratio of 1.9 between plasma and cell levels and a mean of 0.35 μg/100 ml was found in healthy persons (Friberg et al., 1974). Similarly, Friberg et al. (1973) reported a mean value of 0.49 μg/100 ml in normal, healthy children.

Bogden et al. (1974) assayed whole blood of inner-city children in Newark, New Jersey, for cadmium, lead, and zinc and determined frequency distributions for each metal. The mean concentration of cadmium (0.3 μg/100 ml) found in 369 analyses is somewhat lower than values found in other studies reported by Bogden (Table 5.5). Significant correlations were found between whole blood concentrations of zinc and cadmium and between concentrations of lead and cadmium. Paint is suggested as the major source of ingested lead and cadmium and air as a respiratory contaminant for all three metals.

TABLE 5.5. WHOLE BLOOD ASSAYS[a]

Population Tested	Cadmium, μg/100 ml Mean	Cadmium, μg/100 ml Range
Hospitalized children	0.5	0.0-1.9
Children with suspected pica	0.6	0.0-7.9
Adult males	0.9	0.3-5.4
Inner city children	0.3	0.0-2.8

[a]Source: Bogden et al., 1974.

Glauser et al. (1976) found living normal humans to have a blood cadmium level of 0.34 ± 0.05 μg/100 ml, while a matched group of living untreated hypertensive humans had a blood cadmium level of 1.1 ± 0.15 μg/100 ml. Workers chronically exposed to cadmium may not only have blood cadmium levels elevated considerably in excess of those observed in "normals" but also the distribution of cadmium within the blood may differ. In contrast to normal persons in whom the majority of cadmium is in the plasma fraction of the blood, exposed workers' blood contains more cadmium in the cells than in the plasma. Friberg et al. (1974) reported a cell-to-plasma ratio of 0.5 and a mean whole blood level of 4.1 μg/100 ml for an occupationally exposed group. Little can be generalized from the studies of exposed workers except that their blood cadmium levels may be markedly elevated. One difficult problem is that individual exposure conditions usually cannot be specified adequately. Secondly, wide fluctuations within some individuals are observed during exposures, while in other co-workers, a more steady level is seen (Friberg et al., 1971). Piscator and Lind (1972) studied a group of 25 workers in an alkaline battery factory in an effort to relate cadmium concentrations in blood to exposure time. Results were negative.

Friberg et al. (1973) have concluded that there were no consistent relationships among the following: (1) between cadmium levels in blood and exposure time, (2) between blood levels and body burden, (3) between degree of proteinuria and blood levels, and (4) between levels of cadmium in blood and urinary excretion of cadmium.

Cadmium in the Renal Cortex

Friberg et al. (1973) reviewed several studies which estimated the average cadmium levels in the renal cortex for United States adults aged 50 to 75. Most of these estimates lie in the range of 25 to 50 ppm wet weight. These values are perhaps slightly higher than those reported by Sweden, United Kingdom, and Europe; however, they are much lower than the 90 to 125 ppm wet weight which has been reported for comparably aged Japanese in nonpolluted areas (Friberg et al., 1973).

Livingstone (1972) studied renal accumulations of zinc, cadmium, and mercury to determine the distribution of the metals within the various tissue layers of the kidney (Figure 5.1). The specimens were obtained from an individual who died from a gunshot wound, not kidney disease. In all samples, there was a decreasing concentration gradient from the outer surface of the cortex to the medullary surface for zinc, cadmium, and mercury. Such findings suggest that much of the variability in the reported values may be due to lack of a standardized sampling technique and sampling location among studies. Since the cortex is the area of the kidney which would be expected to show the most variability, the sampling location within the cortex may be an important factor. Because concentrations of all three metals increase toward the outer surface of the cortex, analyses of samples of gross kidney tissue, which included medulla or calices, may yield results which are consistently low relative to cortical concentrations. This study found a median concentration for renal cadmium in adults which was 900 times that found in infant tissues.

Morgan (1972), in establishing the "normal" lead and cadmium content of the human kidney, assayed kidneys which were collected at postmortem examination from 100 unselected autopsies (32 blacks and 68 whites) between October, 1967, and March, 1968, at the Birmingham, Alabama, Veterans Administration Hospital. The mean age for the entire group was 62 years. The mean cadmium concentration for all subjects was 2,359 ppm of ash (with a range of 109 ppm); for blacks, 2,267 ppm, and for whites 2,667 ppm of ash. On the basis of present data, Morgan concludes that 5,000 ppm of ash should be considered the upper limit of "normal" for cadmium but that further analysis might indicate that this figure is still too high.

Hammer et al. (1973) report as follows:

(1) Renal cadmium levels increased over tenfold from infancy to middle age and then declined somewhat thereafter (Table 5.6).

(2) Average renal cadmium and zinc levels increased progressively with increasing smoking intensity (Table 5.7).

(3) Average renal cadmium concentrations in males generally exceeded those of females (Table 5.8).

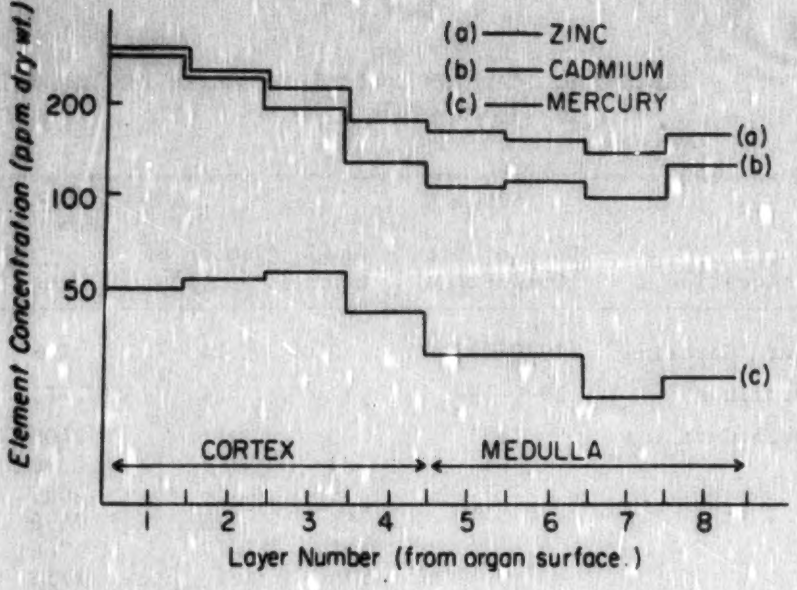

Figure 5.1. Zinc, cadmium, and mercury distributions in the kidney of a 42-year-old female (cause of death: gunshot wound to head). [Reprinted from Proceedings of University of Missouri's 5th Annual Conference on Trace Substances in Environmental Health (D. D. Hemphill, Editor) by H. D. Livingstone, by permission of Environmental Toxic Substances Center, University of Missouri. Published 1972].

TABLE 5.6. CADMIUM CONCENTRATIONS IN THE HUMAN RENAL CORTEX, BY AGE[a]

Location	Date of Data Collection	Age, Mean	Number of Samples	Concentration, ppm, by weight[b]	
				Mean	Range
South Carolina	1970-1971	2	14	188	21-489
Carolinas	1970-1971	17	4	1051	551-1891
North Carolina	1970	23	12	1408	934-3164
		34	7	2338	1282-3350
		45	16	2063	710-3347
		55	13	2696	1230-3525
		65	17	1768	608-3000
		75	12	1755	455-4771
		85	3	1267	940-1512
		91	1	596	--

[a] Source: Hammer et al., 1973.

[b] Tissue from adult autopsy materials was obtained from seven North Carolina hospitals in 1970. Pediatric tissues were from the Medical College of South Carolina in Charleston.

TABLE 5.7. RENAL CADMIUM AND ZINC LEVELS IN 40- TO 79-YEAR-OLD MALES, BY SMOKING CATEGORY[a]

Smoking Category[b]	No. of Samples	Metal	Concentration, ppm ash weight		
			Level ± SD[c]	Median	Range
Never smoked	10	Cadmium	1286 ± 404	1286	710-1823
		Zinc	2511 ± 544	2519	1759-3278
<1/2 pack daily	6	Cadmium	2132 ± 592	2144	1303-2891
		Zinc	3052 ± 345	2923	2526-3429
1/2 to 1 pack daily	8	Cadmium	2795 ± 1045	2086	1752-4771
		Zinc	3513 ± 1931	2980	2306-8050
>1 to 1-1/2 packs daily	5	Cadmium	2812 ± 946	2650	1562-4000
		Zinc	3551 ± 2064	3237	1682-7000

---

[a] Source: Hammer et al., 1973.

[b] Smoking history was queried for the last 5 years of the patient's life only.

[c] SD = Standard deviation.

TABLE 5.8. CADMIUM IN RENAL CORTEX, BY SEX AND AGE[a]

Age Interval in Years	Cadmium in renal cortex[b], ppm ash weight						Male to Female Ratio
	Males			Females			
	No. of Samples	Mean	Range	No. of Samples	Mean	Range	
10-19	2	1221	551-1891	2	881	832-929	1.39
20-29	8	1469	972-3164	4	1285	934-1622	1.14
30-39	4	2601	1797-3350	3	1988	1282-2530	1.31
40-49	10	2064	710-3347	6	2062	1268-3200	1.00
50-59	9	2941	2000-4000	4	2197	1230-2850	1.34
60-69	12	1743	860-3450	4	1804	608-3000	0.97
70-79	8	1878	768-4771	4	1509	455-3700	1.24
80-89	1	940	768-477	2	1431	1350-1512	0.66

---

[a] Source: Hammer et al., 1973.

[b] Excludes 15 subjects with cancer--one with schleroderma and one with acute hepatitis and pancreatitis.

(4) Increases in renal zinc concentration are related to cadmium virtually on a one-to-one basis (Figure 5.2).

(5) As shown in Table 5.9, cancer patients had a significantly more variable renal cadmium concentration [F(16,57) = 3.18 p<0.005] and a significantly less variable hepatic cadmium concentration [F(57,16) = 6.50 p<0.001].

(6) Hepatic cadmium increased four- to fivefold from infancy to adulthood but remained relatively constant thereafter (Table 5.10).

(7) Hepatic cadmium was significantly higher in 40 to 70-year-old males with any smoking history when compared to those with no smoking history.

Repeated exposures to cadmium among workers may cause accumulation of cadmium in the organs, particularly the kidneys. Cadmium accumulation of 200 ppm in the renal cortex is believed to be the critical level needed to produce renal tubular dysfunction (Friberg et al., 1973). Renal tubular damage leads to an increase in urinary cadmium excretion. Adams et al. (1969) found 0 to 168 ppb in urine in 56 workers exposed to cadmium oxide dust. Generally, a large degree of individual variation has been observed among exposed workers.

Table 5.11 illustrates cadmium concentration in renal cortex at autopsy and the associated morphological changes observed in workers exposed to cadmium oxide dust. Profound morphological changes occurred in persons having greater than 15-year exposure. These same workers also tend to have much lower levels in the cortex, probably reflecting the greater release of cadmium from the kidneys following the onset of proteinuria (Friberg et al., 1974). Adams et al. (1969) have reported that proteinuria frequently persists after exposure to cadmium has ceased and urinary cadmium excretion has decreased.

EXCRETION OF CADMIUM

Urinary excretion of cadmium is considered the major route for body burden-related elimination (Friberg et al., 1974). Reported values for cadmium are extremely variable; however, recent studies suggest an average normal urinary excretion of cadmium of 1 to 2 μg/day (Friberg et al., 1974). Table 5.12 summarizes the results of studies of urinary excretion in persons without known industrial exposure. Cadmium levels reported in urine of occupationally exposed workers range from 0 to 1,000 μg/day. There is no evident relationship between urinary cadmium excretion in exposed workers and the degree of exposure. Some workers had been exposed to cadmium in sufficient quantity to cause considerable tissue accumulation, yet had urinary levels of less than 2 ppb (Friberg et al., 1974). Due to the wide individual scatter, Friberg et al. (1975) concluded that there were no data which show that concentrations of cadmium in blood or urine can be used for

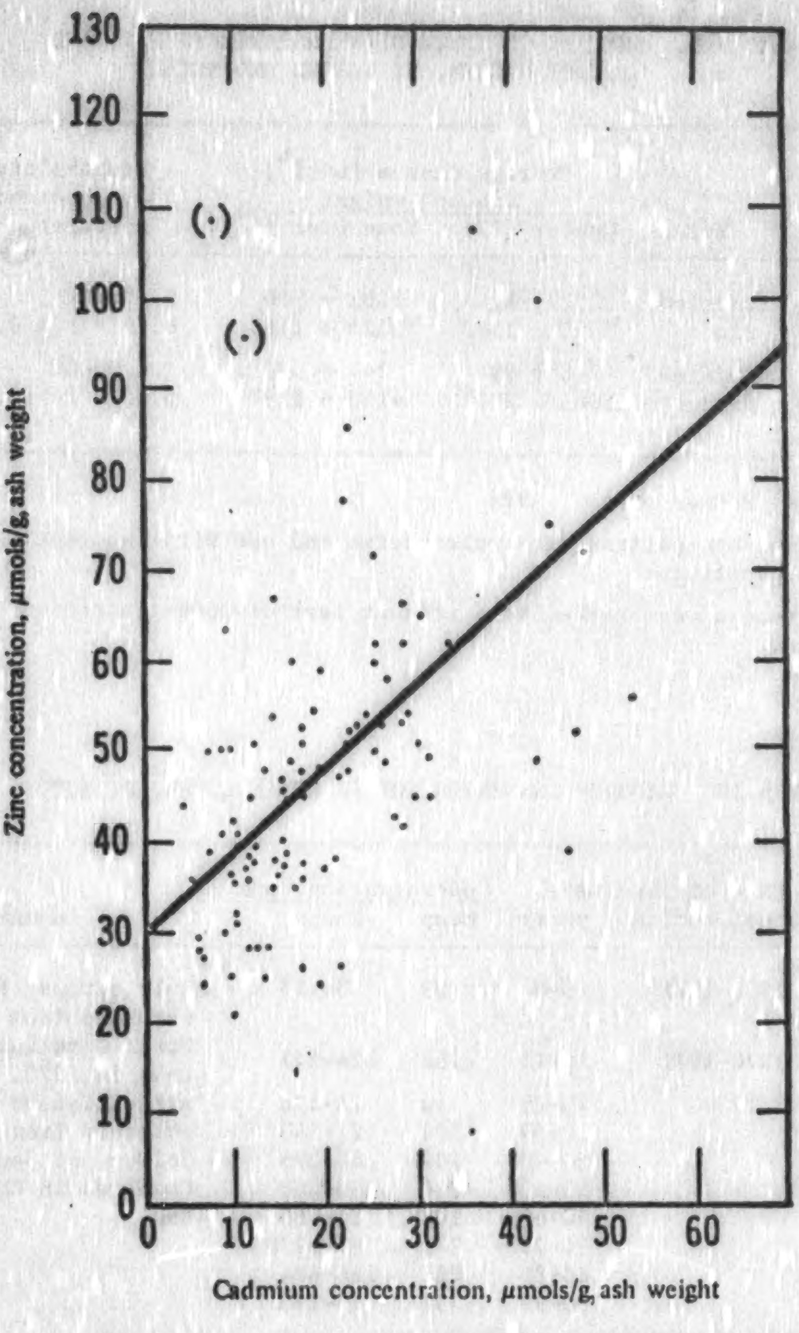

Figure 5.2. Molar relationship of cadmium and zinc in the renal cortex (Hammer et al., 1973).

TABLE 5.9. SUMMARY OF TESTS BETWEEN PATIENTS WITH AND WITHOUT CANCER, BY TISSUE AND METAL[a]

Tissue	Metal	Average tissue level[b], ppm ash weight		Probability of Observed Difference
		Cancer (17)	Noncancer (58)	
Kidney	Cadmium	3232 + 1744	2061 + 960	$P < 0.01$
	Zinc	3653 + 1368	3020 + 1165	$0.10 > P > 0.05$
Liver	Cadmium	248 + 99	244 + 53	$P < 0.80$
	Zinc	5063 + 2871	4120 + 2181	$0.60 > P > 0.40$

[a] Source: Hammer et al., 1973.

[b] Includes one patient with scleroderma and one with pancreatitis and hepatitis.

[c] Differences were tested by a student test of long-transformed data.

TABLE 5.10. CADMIUM CONCENTRATION IN HUMAN LIVER, BY AGE[a]

Location	Date of Data Collection	Age, years	Concentration, ppm		Remarks
			Mean	Range	
South Carolina	1970-1971	0-9	39	8-115	Adult autopsy tissues obtained from seven North Carolina hospitals in 1970. Pediatric tissues were obtained from Medical College of South Carolina in Charleston.
Carolinas	1970-1971	10-19	168	124-247	
North Carolina	1970	20-29	140	21-396	
		30-39	194	21-343	
		40-49	197	58-375	
		50-59	206	73-368	
		60-69	198	21-460	
		70-79	273	65-1720	
		80-89	282	168-684	
		90-99	97	21-173	

[a] Source: Hammer et al., 1973.

TABLE 5.11. CONCENTRATIONS OF CADMIUM IN KIDNEY CORTEX IN WORKERS EXPOSED TO CADMIUM OXIDE DUST IN RELATION TO MORPHOLIGICAL KIDNEY CHANGES SEEN AT AUTOPSY OR BIOPSY[a]

Worker	Morphological Changes[b]	Proteinuria[c]	Cadmium in Cortex[d], μg/g wet weight	Age	Years Exposed	Years Since Last Exposure	Year of Autopsy or Biopsy
							Autopsy
S.W.H.	++	+	83	46	28	1	1960
K.J.	++	+	75	49	22	9	1951
K.N.	e	+	20	57	18	6	1952
H.B.	++	+	33	60	26	3	1949
A.B.	++	+	174	39	16	4	1950
O.J.	++	+	63	62	20	1	1967
							Biopsy
G.J.	(+)	+	321	44	11	12	1959
G.K.	(+)	+	152	46	15	0	1959
A.L.	--	(+)	220	36	6	0	1959
E.Y.	--	--	446	39	7	0	1959
E.H.	--	+	320	40	15	10	1959
J.P.	--	+	330	43	20	6	1959
N.U.	--	--	180	44	12	0	1959
H.N.	--	+	21	45	13	0	1959
K.N.	--	--	190	50	15	2	1959

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[a] Reprinted from Cadmium in the Environment, 1st Edition, L. Friberg, L. M. Piscator, and G. Nordberg, (c) CRC Press, Inc., 1971. Used by permission of CRC Press, Inc.

[b] -- = No morphological changes
(+) = Slight morphological changes
++ = Profound morphological changes.

[c] -- = Negative results on repeated testing with trichloracetic acid
(+) = Varying results
+ = Positive results on repeated testing.

[d] Underlined figures are based on cadmium concentrations in whole kidney, assuming that the cadmium concentration in cortex is 1.5 times the average kidney concentration.

[e] Results from histological examinations not reported but in an examination in 1946, this worker had the lowest kidney function tests of all.

TABLE 5.12. URINARY EXCRETION OF CADMIUM IN "NORMAL" SUBJECTS[a]

Country	No. of Samples	Age Group	Concentration Mean	Concentration SD[b]	Concentration Range	Units	Method
United States	154		1.59		<0.5-10.8	ppb	Spectrographic after dithizone extraction
Japan	30		3.1		0.0-15.9	ppb	Dithizone
Gifu	46	4-6	0.47	0.25		ppb	Atomic absorption spectroscopy after extraction
	40	9-10	0.65	0.45			
	41	14-15	0.72	0.50			Ditto
	56	20-29	0.99	0.63			"
	37	30-39	1.13	1.06			"
	40	40-49	1.76	1.33			"
	43	50-59	1.75	1.38			"
West Germany	14		1.0			ppb	Dithizone
	15		0.98		0.34-1.57	µg/24 hr	Atomic absorption spectroscopy after MIBK-APDC extraction
	169[c]		1.25		0-5	µg/g creatinine	Ditto
Belgium	44		0.95	0.8		µg/g creatinine	Atomic absorption spectroscopy after extraction
Sweden	10	20-47	0.39		0.05-0.77	µg/24 hr	Atomic absorption spectroscopy after MIBK-APDC extraction
	88	50-59	0.62		0.1-2.0	µg/g creatinine	Atomic absorption spectroscopy after extraction
	10	15-16	0.25		0.2-0.5	ppb	Ditto
	10	15-16	0.21		0.1-0.3	µg/g creatinine	"
	10[d]	34-63	1.7		0.4-3.7	µg/g creatinine	"

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[b] SD = Standard deviation.

[c] Includes both children and adults; values for children did not differ on an average from those of adults.

[d] Workers without known industrial exposure to cadmium but living in a cadmium-contaminated area.

estimating levels of cadmium in human beings. It is not possible to use a fixed level of cadmium in blood or urine to be used for analytical control of (1) exposed workers or (2) populations exposed to cadmium in food or ambient air. Concentrations of cadmium in urine above "normal" would indicate that signs of cadmium-induced renal dysfunction had already occurred, provided other reasons for the increased excretion could not be demonstrated.

As shown in Table 5.13, a comparison of cadmium levels in the blood and urine of 100 acculturated and 90 unacculturated individuals shows markedly lower levels of cadmium in the unacculturated population (Hecker et al., 1974). The technologically developed population consisted of 100 Red Cross donors, ages 18 to 58, from Ann Arbor, Michigan. The unacculturated population consisted of 137 Yanomamo Indians living in the area drained by the Upper Orinoco River and its tributaries in southern Venezuela. Cadmium was determined by anodic stripping voltammetry (Table 5.13).

TABLE 5.13. CADMIUM LEVELS IN ACCULTURATED AND UNACCULTURATED POPULATIONS[a]

Population	Matrix	Statistic	Cadmium
Ann Arbor	Blood	Number of subjects	47
		Range	<0.1-9.6[b]
		Mean	1.71[b]
		SD[c]	1.89[b]
Yanomamö	Blood	Number of subjects	90
		Range	0.07-3.72[b]
		Mean	0.57[b]
		SD[c]	0.51[b]
	Urine	Number of subjects	47
		Range	0.0-4.5[d]
		Mean	1.2[d]
		SD[c]	1.2[d]

[a] Source: Hecker et al., 1974.

[b] Values in μg/100 ml.

[c] SD = Standard deviation.

[d] Values in μg or ppb.

Fecal excretion of cadmium has been estimated at 31 μg/day by Friberg et al. (1974) and 42 μg/day by Tipton and Stewart (1969). These values include unabsorbed dietary cadmium. Tracer studies show that less than 0.1 percent of a retained oral dose of ^{115m}Cd was excreted in feces (Rahola et al., 1972). High concentrations of cadmium in bile from autopsy samples suggests an enterohepatic circulation of cadmium in man. Animal studies suggest also that less than 5 percent of fecal excretion could be accounted for by this route (Friberg et al., 1974). At present, the precise mechanisms for fecal excretion of cadmium in human beings are not known (Friberg et al., 1974).

Other possible routes of cadmium excretion include milk, saliva, and hair. Excretion of cadmium into milk of nursing mothers may be of some significance in body clearance of cadmium. Pinkerton et al. (1973) showed that cadmium concentrations in human milk ranged from 0.0088 to 0.1335 ppm with a median value of 0.0111 ppm. Cadmium may also be secreted into human saliva. Friberg et al. (1973) reported concentrations of up to 0.1 μg/g in human saliva. Hammer et al. (1971) have suggested using hair as an indicator of exposure to various trace metals, including cadmium. Ten-year-old boys from five cities ranked according to trace metal contamination supplied the hair samples. As can be seen from Table 5.14, there is good agreement between exposure levels and cadmium levels in hair. Another study conducted by Schroeder and Nason (1969) investigated the influence of age, sex, and hair color on levels of cadmium in hair. Their results showed differences in cadmium content related to hair color,

TABLE 5.14. CADMIUM IN HAIR FROM BOYS LIVING IN URBAN AREAS[a]

Exposure Ranking[b], city	Number of Determinations	Geometric Mean, ppm
I High	45	2.1
II High	25	1.5
III Low[c]	37	1.0
IV Low	21	1.0
V Low	37	0.7

[a] Source: Hammer et al., 1971.

[b] Ranking determined by combining aerometric, geologic, and industrial data.

[c] Low approximates usual U.S. urban level.

sex, and age. Black-haired males had less cadmium in their hair than those with brown, blonde, or red hair. In women, gray hair had less cadmium than either natural-color hair or gray hair obtained from males. Also, cadmium, nickel, and lead did not accumulate with age. The authors concluded that concentration of cadmium in hair probably does not reflect tissue stores under normal conditions (Schroeder and Nason, 1969). Petering et al. (1973) investigated the relationship of age and sex to cadmium in human hair. Regression analysis showed two groups of males with respect to cadmium concentration in hair, namely those over and under 12 years of age. Similar analyses indicated that hair cadmium distribution for females delineated one group below and one group above 50 years of age. The authors conclude that comparisons of metallic content of hair in humans should be limited to a narrow age range and to one sex.

Table 5.15 presents findings from several studies of cadmium in hair, showing the typical values and ranges observed. Analysis of metals in hair also presents additional difficulties in that external contamination from dust and from metals in hair sprays, hair coloring products, etc., must be taken into account (Friberg et al., 1974).

Johnson et al. (1975) conducted an epidemiological survey in the metropolitan area of Houston, Texas, on cadmium, lead, zinc, manganese, and copper. Six groups, with 36 individuals in each group, were monitored, three exposed, and three corresponding controls:

Exposed	Control
I. Policeman on foot patrol	IA. Office workers in downtown Houston
II Garage attendants	IIA. Orderlies and custodians
III. Females living within two blocks of a freeway	IIIA. Females living away from a freeway.

Each subject was sampled four separate times for blood, urine, and hair.

As shown in Table 5.16, there appeared to be wide variations in cadmium content, particularly in hair. Statistical comparison of the data indicated that there were significant differences in cadmium levels in urine between Group I and IA and Group II and IIA at the 95 percent confidence limits. No differences were seen in the female subjects. Conceivably, the levels of cadmium in urine are related to the exposure to air pollutants.

BIOLOGICAL HALF-LIFE

The extremely long biological half-life of absorbed cadmium in the body results in essentially continuous accumulation throughout life (Hammons and Huff, 1975). Cadmium becomes bound to the protein metallothionein in the kidney, and accumulates until the fifth or sixth decade of life, after which it begins to diminish in concentration (Environmental Health Resource Center, 1973). Estimates of half-life can be made on a group basis by comparing body burden and excretion. In the United States, body burden has

TABLE 5.15. "NORMAL" CONCENTRATIONS OF CADMIUM IN HAIR[a]

			Concentration, μg/g			
Country	Sex	No. of Samples	Mean SD[b]	Median	Range	Method
U.S.A.	Male	82	2.77 ± 4.37			Atomic absorption; hair not treated with detergent solution
	Female	47	1.77 ± 1.64			
	Male children[c]	45	3.5 ± 4.94	2.1		Atomic absorption; hair pre-treated with EDTA
		25	2.0 ± 1.54	1.6		
		37	1.3 ± 0.99	1.0		
		21	1.3 ± 1.30	0.9		
		37	0.9 ± 0.8	0.8		
Sweden	Male	7	0.44 ± 0.14	0.43	0.24–0.60	Atomic absorption; hair pre-treated with detergent
	Female	8	0.87 ± 0.26	0.92	0.41–1.27	
Yugoslavia	Male	17	0.54 ± 0.27	0.45	0.20–1.48	Ditto

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[b] SD = Standard deviation.

[c] Ten years of age from five areas with differing degrees of cadmium contamination.

TABLE 5.16. CADMIUM IN BLOOD, URINE, HAIR, AND FECES[a]

Group	Blood, μg/100 ml		Urine, μg/ℓ (ppb)		Hair, μg/g		Feces, μg/g	
	Mean	SD[b]	Mean	SD	Mean	SD	Mean	SD
I	0.5	0.67	1.4	1.05	1.1	2.09	0.19	0.07
IA	0.7	0.85	0.6	0.44	1.1	2.02	0.20	0.11
II	0.5	0.52	0.8	0.63	1.0	0.97	0.30	0.21
IIA	0.4	0.44	0.5	0.23	2.2	2.10	0.24	0.13
III	0.9	1.1	0.6	0.67	0.6	0.41	0.27	0.16
IIIA	0.8	1.7	0.6	0.40	0.7	0.55	0.23	0.13

[a] Source: Johnson et al., 1975.

[b] SD = Standard deviation.

been estimated to range from 15 to 20 mg of cadmium. Urinary excretion amounts to 1.6 ppb, corresponding to a daily excretion of 0.012 to 0.015 percent of body burden. Such findings would place the biological half-life somewhere between 13 and 47 years (Friberg et al., 1974).

Friberg et al. (1974) have computed similarly long biological half-lives of 19 to 38 years, using mathematical models. The validity of some of the assumptions of these models (i.e., excretion rates and body burden values) is still open to question and, as Friberg et al. (1974) conclude, the exact biological half-life of cadmium is still uncertain.

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